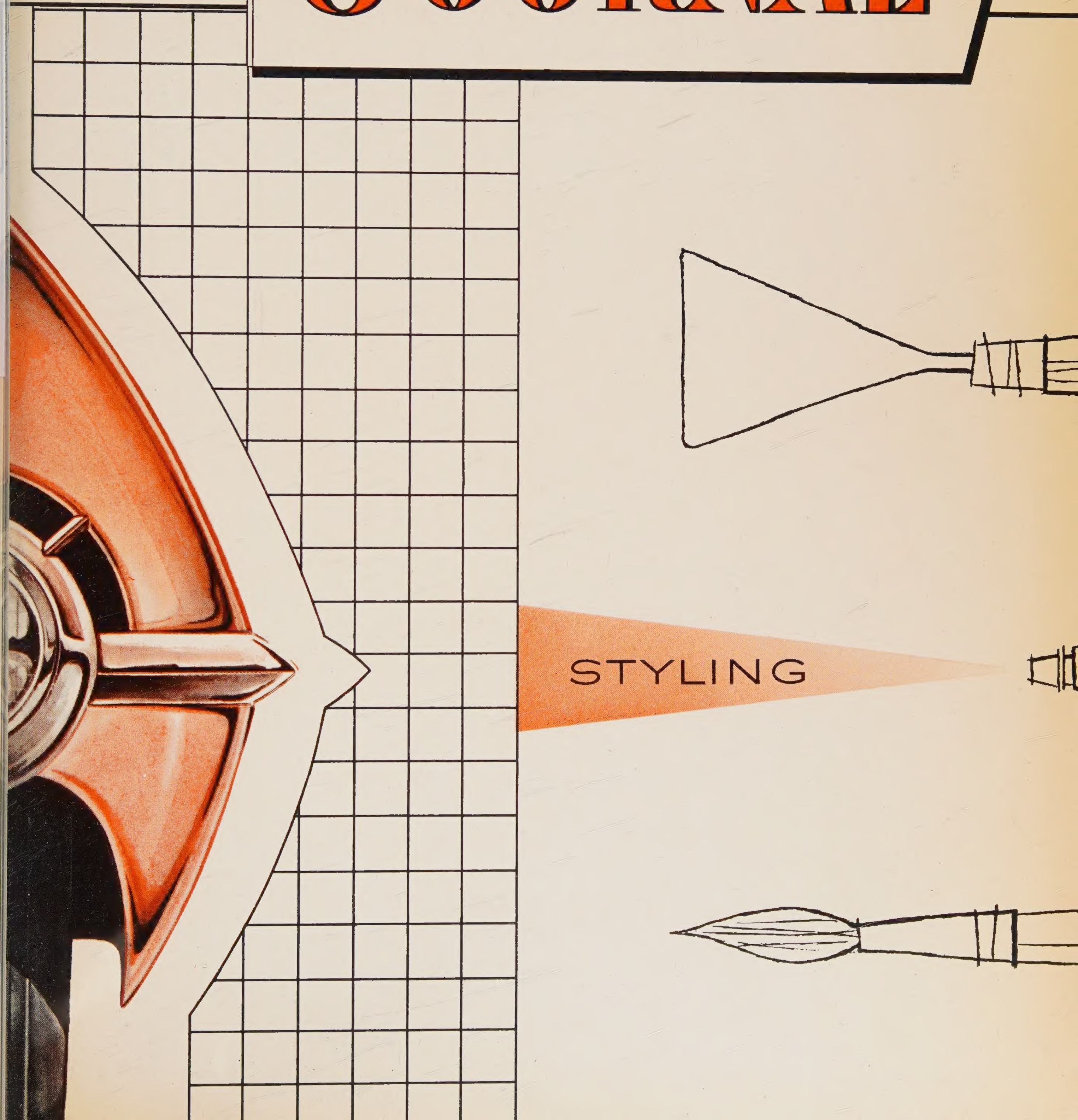
GENERAL MOTORS Engineering JOURNAL

Volume 2 January-February 1955 Number 1



STYLING

On Automotive Engineering and Model Changes

JANUARY is a month for looking ahead.

In General Motors it brings the opening of our Motorama to climax the introductions of our outstanding new 1955 car lines.

Sometimes people ask why we have annual model changes. I recall the answer which I gave just two years ago at a luncheon for business leaders held in connection with the New York opening of the 1953 Motorama.

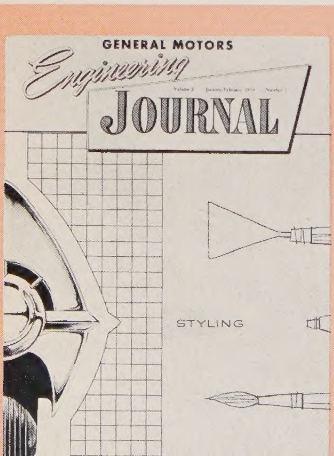
I said it was my considered opinion that "The annual model changes have been perhaps the most important single factor responsible for the growth of our industry. Under the forced draft of these periodic model changes competition has been stimulated and technological progress speeded up. Efficiency has been increased and the level of buying power raised. The industry has grown, employment has mounted and, finally, the annual model change has made available a sufficient number of used cars to bring individual transportation within the reach of everyone."

It is obvious that the annual improvement in automotive transportation that brings benefits to millions of car buyers would not be possible without the contribution of the automotive engineer. Conversely, the necessity of making changes each year has been a tremendous challenge as well as a great opportunity for the engineer.

Covering the period just since the war, consider the improvements that have come off the drawing boards and out of the laboratories—the V-8 high compression engine, improved automatic transmissions, power brakes, power steering, air conditioning, panoramic windshields, to name a few.

Even now our engineers are working on improvements for 1956 and 1957—and even 1958. Who can forecast what the years beyond will bring? I have no doubt, however, that some of the developments of the future will come from today's students of engineering educators who are readers and users of this periodical, now just entering its second full year. As graduates from engineering colleges some of them will join General Motors and infuse that new blood into our engineering and research departments that is so necessary to keep the automobile industry an industry of constantly advancing technology.

Harlow H. Curtice
President,
General Motors Corporation



THE COVER

This issue's cover was created by General Motors Styling. The brush, air brush and modeling tool represent the aesthetic aspects of styling. The grid template represents the technical aspects of styling. The car suggests the results of these creative efforts. In addition to automobiles, many other products and activities reveal the work of styling. In General Motors, some of these include trucks, locomotives, off-the-road vehicles, household appliances and exhibits.

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A Study of Applied Gear Design: Speedometer Gears of Different Ratios in Pontiac Transmissions

Gear design has developed into a specialized mathematical science which has become standardized with respect to many of the mathematical relationships between various gear dimensions such as diameters, leads, and center distances. Although this system of mathematical standards is helpful to the gear designer, it has not replaced the need for an understanding of the basic principles of gear tooth action. Situations often arise in gear design which cannot be met by the use of standard gears. Such an application is found in the transmission of the 1955 Pontiac automobile in which several gear designs are required for a pair of gears used to drive the speedometer mechanism. Here was an example of how the gear designer had to apply both the basic principles of gear tooth action and the mathematical relationships growing out of those principles to design a gear that met the demands of satisfactory operation and efficient car assembly.

Modern gear design is an exacting mathematical science, very closely related to the manufacturing process used in the production of the gears being designed. This is true because as a gear is designed, so will it be generated or cut.

However, there are some compromises which need to be made in gear design and it is because of these compromises that the standard-design gears will not suffice in the majority of applications. There are compromises to be made for strength, operational smoothness and quietness, space limitations, and manufacturability; moreover, there are even compromises to be made in the basic design calculations.

By applying basic gear design principles, these compromises can be accounted for mathematically, and limits placed upon them. These basic principles involve the fundamentals of gear tooth action but are too often neglected in favor of getting a quick answer from a standard system. Analyzing gear tooth action is often necessary to properly design, proportion, and dimension a pair of gear teeth.

Compromises of this sort were present in the design of certain gears—located in the transmission of the 1955 Pontiac—used to drive the speedometer mechanism. The design problem involved in these speedometer gears is one of gear ratios.

Pontiac passenger cars are built using one of several rear axle ratios (ratio of the transmission output shaft rpm to the vehicle speed), depending on customer requirements. For each rear axle ratio, the transmission output shaft rotates at a different speed for the same car speed. Changing the vehicle's rear axle ratio, then, requires a change in the gear ratio of the transmission output shaft to the speedometer mechanism, if the same car speed is to be read by the same speedometer mechanism. Usually, when a change in gear ratio is made, both gears are affected if the center distance is to remain constant. In production, however, it would be costly and impractical to maintain banks of transmission assemblies with the speedometer drive gear being the only difference between them. This drive gear on the transmission output shaft is, therefore, held uniform. With two conditions being constant—the driving gear and the center distance between the driving and driven gears—different driven gears with the proper number of teeth must be selected to satisfy the rear axle ratio and speedometer mechanism ratio requirements.

PER CENT ODOMETER ERROR

REAR AXLE RATIO	SPEEDOMETER DRIVEN GEAR: THEORETICAL NUMBER OF TEETH	SPEEDOMETER DRIVEN GEAR: ACTUAL NUMBER OF TEETH	PER CENT ERROR
43–10	22.43	22	+1.95
41–10	21.39	21	+1.85
39–10	20.35	20	+1.75
40–11	18.97	19	−0.15
41–12	17.82	18	−1.00

Table I (Left)—The theoretical number of teeth in the driven gear of the speedometer gear set can be determined mathematically when the rear axle ratio and the number of teeth in the driving gear are known. Since the calculations will result in partial numbers of teeth, the whole number of teeth must be used which gives the least per cent error in odometer and speedometer readings. Selections are made from the chart showing the per cent error for various numbers of teeth in driven gears for various rear axle ratios.

The next step in the speedometer gear problem is the design and manufacture of the various driven gears which mate with the same driving gear. In this case, the fact that a *hob** may be considered as a mating gear means that all of the different gears may be generated with the same hob. To design these various driven gears (having different numbers of teeth) that can be generated with the same hob, then becomes the engineer's problem.

A long established standard guides the designer in the selection of tooth proportions. Spacing, height, and pressure angles have been fixed into systems. The standard has selected values for *pitch line* spacings which are evenly divisible into π and, as a result, there are so-called *diametral pitches* P of whole numbers such as 1, 2, 3, and 4. Then, the standard value for the *addendum* is 1.000 over P and the *dedendum* is 1.157 over P in order to allow for clearance with the mating addendum. The whole system of diametral pitch is somewhat confusing and the definition that diametral pitch is the number of teeth per inch of pitch diameter does little to clarify it. In reality, it is nothing but a numbering system that ties together diameters and center dis-

*For glossary of gear terms, see p. 9.

By **GEORGE E. TOZER**
Pontiac
Motor
Division

Non-standard gears based on fundamental design principles result in efficient car assembly

tances, and *leads* and *helix angles* in the case of helical gears and, in this respect, has its advantages. The existence of the standard diametral pitch system has, in some cases, led the gear designer to believe that all he has to do is to specify diametral pitch and *pressure angle* on his drawing and that everything else will be taken care of as being standard. These incomplete specifications are certainly an indication that such a designer does not know what is going to happen when the gear he designed runs with its mate. The result of such gear designing is that some gears fail to give satisfactory service[1].

Design Considerations

In discussing gear design as applied to the speedometer gear problem, the basic concepts of gear teeth and involutometry, which are well-known to the student of gear design, need not be discussed in this paper. Likewise, a description of the operation of the speedometer mechanism can be omitted.

It is significant, however, to recognize the odometer ratio involved in selecting the proper number of teeth. This ratio, taken from manufacturers' data, is 1,001 revolutions per mile. Another factor to be considered is the tire revolutions per mile which is 745 revolutions per mile for 7.10 by 15 tires. Knowing the rear axle ratio and the number of teeth in the driving gear, the theoretical number of teeth required for the driven gear n_t may be determined as follows:

$$n_t = \frac{N\,T\,R_A}{S}$$

where

N = number of teeth in driving gear
R_A = rear axle ratio
S = odometer revolutions per mile
T = tire revolutions per mile.

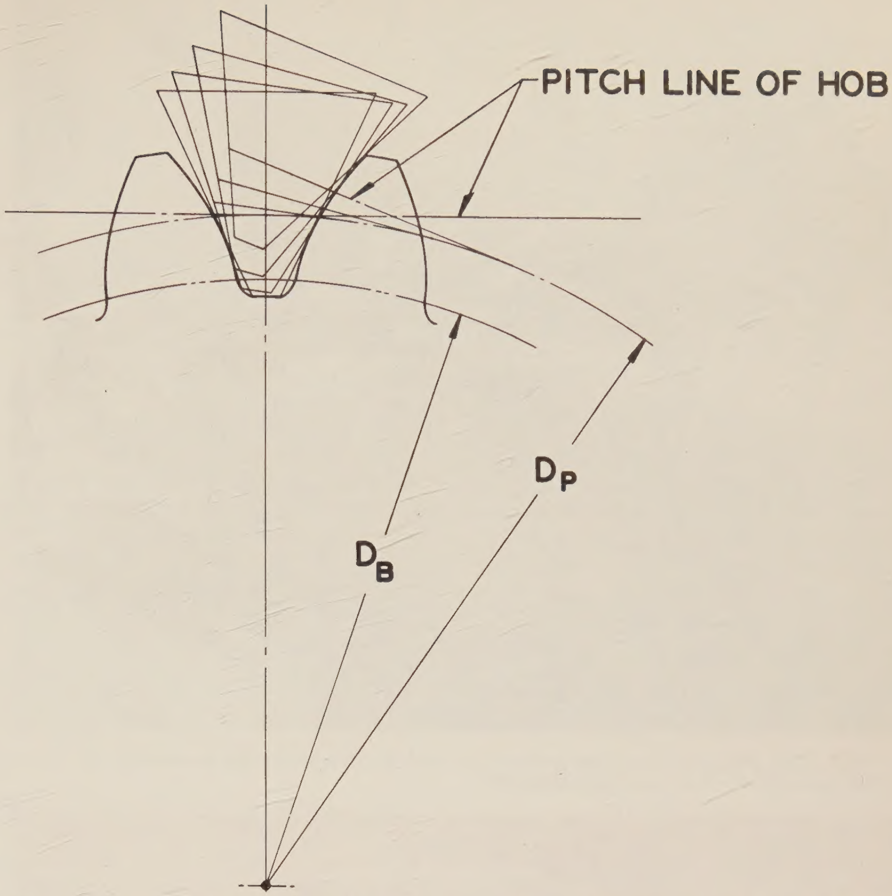

Fig. 1—The involute profile of a gear tooth may be generated by hobbing. Theoretically, the hob may be considered as the basic rack of the gear being generated. The true shape that the hob produces may be illustrated by actually generating the tooth with the hob by rolling it on the pitch circle of the gear, as shown above. This same relative motion is retained in production where the gear and the hob actually are rotated together.

Obviously, partial numbers of teeth, resulting from the use of this equation, cannot be considered for manufacture, and a compromise immediately becomes evident as a high or low odometer reading and a correspondingly fast or slow speedometer reading. The whole number of teeth, which will result in the least per cent odometer error, is selected as the number of teeth to be used. Table I shows the various driven gears for the various rear axle ratios and the resulting per cent error for each case.

In the per cent error column of Table I, it can be seen that there is a positive or negative error, depending on whether the actual number of teeth is above or below the theoretically correct number. From the manufacturer's standpoint, if an error must be present, it is desirable for it to be in the positive direction. However, in some cases, the error in the positive direction is so great that a slight error in the negative direction is acceptable.

The method of manufacture to be considered in the speedometer gear problem is *hobbing* which utilizes a cutter in the form of a worm with cutting teeth of rack-shaped cross section. A hob may be considered as a basic *rack* of the gear being generated and the true shape that it produces may be determined on the drawing board by actually generating the tooth with the hob by rolling it on the *pitch circle* (Fig. 1). Actually, both the hob and the gear are rotating together as the gear is being cut, but the relative motion is the same when the gear is held stationary and the hob rotated about its pitch circle. Fig. 2 shows a hobbing machine generating the steel driven gears used with the Hydra-Matic automatic transmission in 1954 Pontiacs.

Having determined the various numbers of teeth required for each driven gear which will mate with the same driving gear, the speedometer gear problem becomes one of gear design and manufacturing—each of which is dependent upon the other.

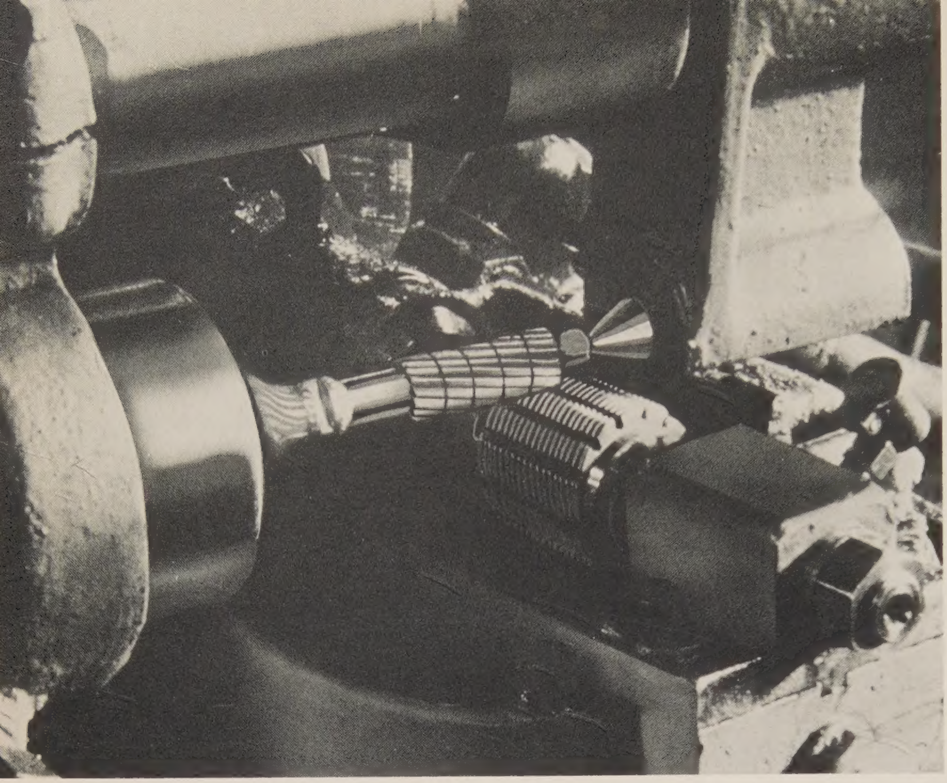

Fig. 2—This gear hobbing machine generates the steel driven gears for the speedometer gear set in Pontiac Hydra-Matic automatic transmissions.

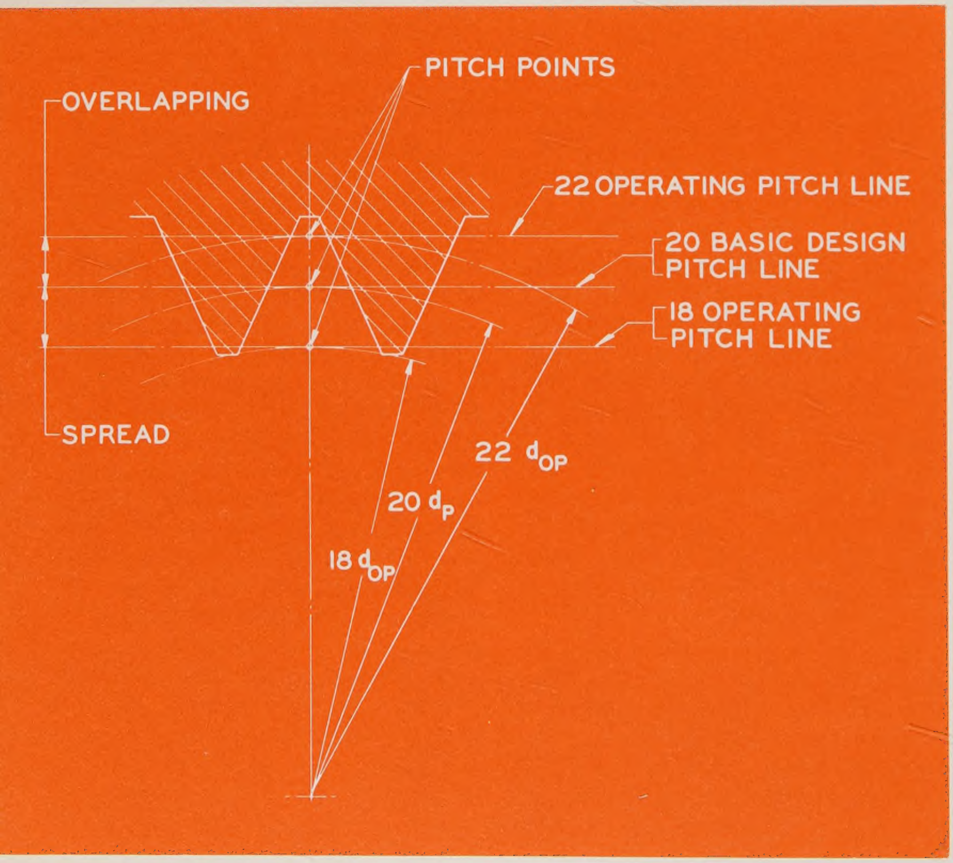

Fig. 3—Overlapping and spread pitch circles are illustrated in this diagram of a rack tooth and its corresponding pitch lines and driven gear pitch circles. The design pitch line and design pitch circle are shown for the 20-tooth driven gear of the basic design set of gears. As the gear ratio is increased or decreased by using a different number of teeth in the driven gear, the operating pitch circles become larger or smaller but remain tangent to the operating pitch line at its pitch point.

Analysis of the Problem

As a problem in applied gear design, the speedometer gear problem with all its compromises required the application of fundamental relationships. Only one theoretically correct set of gears can exist for one center distance when one of the gears is held constant. This particular set is known as the *basic design set* and it includes the driving gear and one of the driven gears. Now come the compromises. So that all compromises will not be in the same direction, whether positive or negative, the mean number of teeth in the particular range being considered is selected as the number of teeth for the basic design set, which in this case is the 20-tooth driven gear.

In the design of the basic set, relationships such as pressure angles, pitch circles, helix angles, and leads are established. In the case of the driving gear, then, these relationships will remain unchanged. It is conceivable that gears with different numbers of teeth may be designed to run with one driving gear. It is likewise conceivable that if the center distance is held constant the pitch circles will change, and if the pitch circles change then the pressure angles and helix angles also will change because they are related to the pitch circle. However, a pitch circle has already been established for the driving gear and it has been generated with a hob about this pitch circle. For purposes of distinction, then, this pitch circle will be referred to as the basic design pitch circle. Then, as the gear ratio is increased or decreased by using a different number of teeth in the driven gear, the pitch circles will become larger or smaller as shown in Fig. 3 which shows a rack tooth and its corresponding pitch lines and driven gear pitch circles. These pitch circles are known as operating pitch circles and Fig. 3 illustrates that in each case the operating pitch circle is tangent to the operating pitch line at its pitch point. Then, if the operating pitch circles of the driven gears are considered relative to the basic design pitch line of the driving rack, they may be said to be either *overlapping* or *spread* away from the basic design pitch line as the ratio of the driving and driven gears is increased or decreased from the ratio of the basic design set. The procedure in determining gear relationships of both the spread and overlapping pitch circle gears is the same, except for determining the tooth thickness later in the design.

In the speedometer gear problem, the gears operate at a shaft angle of 90°; consequently, in the plane of rotation of the driven gear, the pitch circle of the driving gear is projected as a pitch line. The driving gear may be considered as the basic rack of the driven gear. Hobs are manufactured in accordance with the standard diametral pitch system and, in this case, a normal pressure angle of 25° and a normal diametral pitch of 26 in. were selected to be used. The center distance is established in the transmission case and in this particular problem is 1.349 in. The number of teeth in the driving gear is seven teeth. It should be noted that the pressure angle, the diametral pitch, and the center distance are chosen to satisfy acceptable design conditions. Any one or all of them can be changed to satisfy these conditions. For the purpose of this paper, however, it will be assumed that the values as mentioned above result in an acceptable design, and with this information the relationships can be established between the driving gear and the basic design, 20-tooth, driven gear.

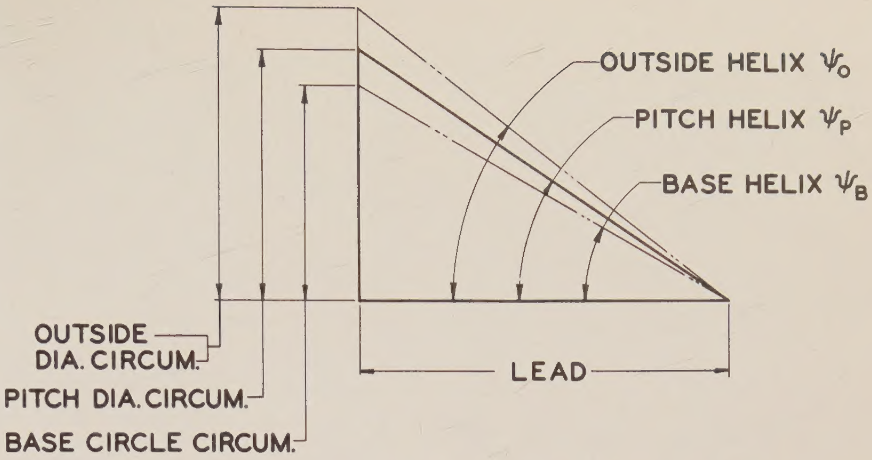

Fig. 4—The lead of a helical gear, as in a screw thread, is defined as the amount of axial advance of a point on the tooth in one complete turn. Lead is used for setting up the hobbing machine in the calculations involved for selecting the indexing gears and feed gears of the machine. Shown above is the *constant lead triangle*, wherein the lead is one leg of a right triangle while the circumference of a diameter of the gear is the other leg and the helix angle at this diameter is opposite the circumference. This diagram demonstrates that the lead is constant over the tooth profile corresponding to a particular diameter whether it be the pitch circle, the base circle, or any arbitrary diameter.

Basic Design Relationships

Helix Angles and Design Pitch Circles

The first basic relations to be established are the helix angles ψ_1 for the driving gear and ψ_2 for the driven gear. These angles are factors in the equations for finding the pitch diameter d_p for the driven gear and for finding the pitch diameter D_P for the driving gear. (In these equations capital letters refer to the driving gear and small letters the driven gear.) The equations are:

$$D_P = \frac{N}{P_N \cos \psi_1}$$

$$d_p = \frac{n}{P_N \cos \psi_2}$$

and for the center distance C_D

$$2C_D = D_P + d_p$$

where

P_N = normal diametral pitch
N = number of teeth.

Since the sum of the two helix angles must equal the shaft angle and because the shafts are at right angles to each other,

$$\cos\psi_1 = \sin\psi_2.$$

By substituting into and combining the above equations, a constant K, equal to $2C_DP_N$, may be resolved as:

$$2\,C_D\,P_N = K = \frac{N}{\cos\psi_1} + \frac{n}{\sin\psi_1}$$

and utilizing the sine and cosine values for various angles, the helix angle of the driving gear is converged upon. Then, the helix angle of the driven gear is found as the difference of the shaft angle θ and the driving gear helix angle as:

$$\psi_2 = \theta - \psi_1.$$

It should be remembered that these helix angles apply only at the design pitch circle and, consequently, they may be substituted into the first two equations to determine these pitch circles.

Lead

Knowing the design pitch circle diameters and the corresponding helix angles at these diameters, the leads L for both the driving and the driven gears may be determined as:

$$L = \frac{\pi D_P}{\tan\psi}.$$

Pressure Angle

The pressure angle in the plane of rotation of both the driving gear and the driven gear is determined, because it is in the plane of rotation of each gear that it will be generated. It should be remembered that this is the angle that the sides of the hob will be with respect to the vertical centerline of the gear. It should also be remembered that this pressure angle applies only at the design pitch diameter of the gear. The pressure angles may be found as:

$$\tan\phi = \frac{\tan\phi_N}{\cos\psi}$$

where

ϕ_N = normal pressure angle.

Base Circle

Having determined the pressure angle in the plane of rotation, the diameter of the *base circle* of the *involute* D_B may be found as the product of the pitch diameter and the cosine of the pressure angle at the pitch circle as:

$$D_B = D_P \cos\phi.$$

Circular Pitch

Circular pitch P_C is the distance from a point on one tooth to the corresponding point on the next tooth measured on the design pitch circle. It is found by dividing the number of teeth into the circumference of the design pitch circle as:

$$P_C = \frac{\pi D_P}{N}.$$

Base Circular Pitch

The circular distance from one tooth to another is a variable over the tooth profile from the base circle to the outside diameter, dependent upon the number of teeth. However, the circular pitch and the pressure angle at the design pitch circles have been established, so the base circular pitch P_B may be determined as:

$$P_B = P_C \cos\phi.$$

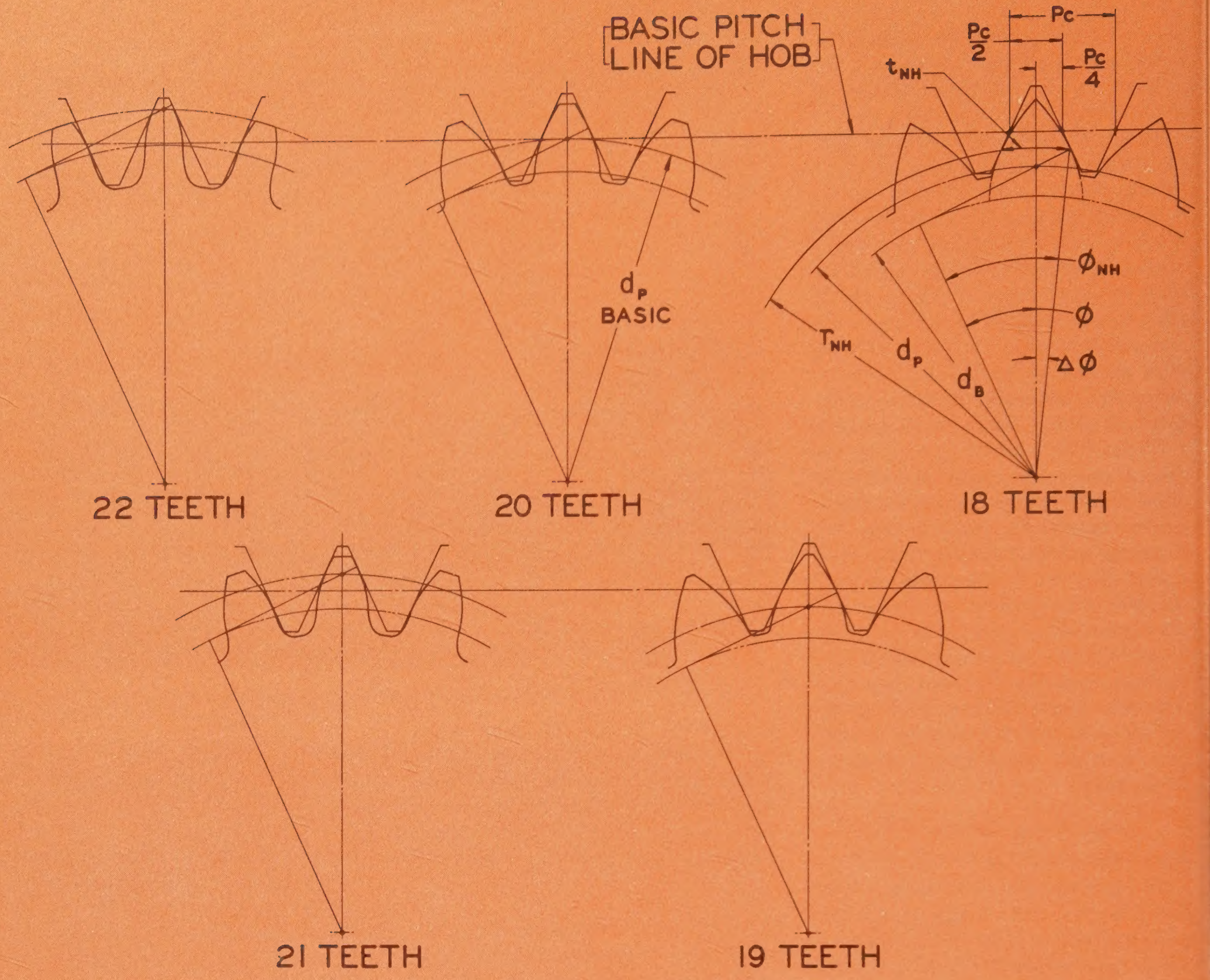

Fig. 5—Tooth thickness at the normal point of hob varies with the number of teeth in the driven gear and must be calculated by trigonometric triangulation. Tooth thickness is the only difference in the calculations for a spread or an overlapping pitch circle driven gear. It can be seen that as the number of teeth are decreased away from the basic design set, the tooth actually becomes pointed as the hob tops it. Conversely, as the number of teeth is increased away from the basic design set, a lower portion of the involute curve is used and the hob undercuts the tooth resulting in a smaller actual length of involute profile. Both the topping and undercutting actions are limiting conditions to lower and higher numbers of teeth.

Tooth Thickness

The tooth thickness, then, at the design pitch circle, when considering zero *backlash*, is one-half the circular pitch or:

$$T_o = \frac{P_C}{2}.$$

If the generating hob is considered to be rotated about the design pitch circle, then at the pitch line of the hob the hob tooth thickness is equal to the hob space thickness; consequently, with zero backlash, the circular gear tooth thickness will equal the gear space thickness.

Backlash

Backlash, according to American Gear Manufacturers Association standards, is measured at the design pitch circle, normal to the plane of rotation of the gear. It is obtained by feeding the hob into the teeth, thereby shaving off a certain amount of involute profile. It is of a value having maximum and minimum limits and is determined by actual experience with the particular application.

If backlash is to be considered in the speedometer gear problem, it is considered in the plane of rotation of the driven gear. The tooth thickness at the design pitch circle of the driven gear is simply the tooth thickness with zero backlash, as determined above, minus the backlash b_L as:

$$t_{BL} = t_o - b_L.$$

Backlash for the driving gear, however, whose plane of rotation is 90° from that of the driven gear, is determined as:

$$B_L = b_L \tan\psi_1.$$

Then, the tooth thickness at the design pitch circle of the driving gear to be used in its manufacture is found as:

$$T_{BL} = T_o - B_L.$$

Spread or Overlapping Design Pitch Circles

Having analyzed the procedure in designing the seven-tooth driving gear and the basic design, 20-tooth, driven gear, the development of other driven gears to run with the same driving gear can be approached in a similar manner. It is important to recognize that the lead of a helical gear is the only value over the tooth profile that remains constant (Fig. 4). Therefore, the lead of the driving gear is the relationship that is used to establish an operating pitch circle of the driven gear. Likewise, it is important to realize that the operating pitch circle is not necessarily the design pitch circle, or the pitch circle about which the gear is generated. But, it can be, as was the case of the basic design 20-tooth gear where the operating pitch circle was the design or generating pitch circle. Upon establishing an operating pitch circle for an 18-tooth gear, the corresponding helix angle at this diameter can be determined, again using the lead of the driving gear in the calculations. When both the operating pitch circle diameter and the operating helix angle of the driven gear are known, then the lead can be found and, when the lead of the driven gear is known, the design or generating helix angle can be found. With the design helix angle established, the design pitch circle diameter at which this helix angle applies can be determined. The equations and relationships for an 18-tooth driven gear can be established in the following manner.

Operating Pitch Circles

The operating pitch circle diameter d_{op}, of the 18-tooth driven gear meshing with the driving worm gear is determined using the lead of the driving gear as:

$$d_{op} = \frac{n\,L}{\pi\,N}$$

and then the operating pitch circle diameter of the driving gear is the remaining portion of the center distance as:

$$D_{OP} = 2C_D - d_{op}.$$

Operating Helix Angles

The operating helix angle ψ_1 corresponding to the operating pitch circle of the driving gear is found, again using its constant lead as:

$$\tan\psi_1 = \frac{\pi\,D_{OP}}{L}$$

and the operating helix angle of the driven gear is the remaining portion of the shaft angle θ or:

$$\psi_2 = \theta - \psi_1.$$

Lead of Driven Gear

Having now established the diameters of both operating pitch circles and the operating helix angle, the all important lead of the driven gear is determined in accordance with the lead triangle as shown in Fig. 4.

$$L_2 = \frac{\pi\,d_{op}}{\tan\,\psi_2}.$$

Design Helix Angle

Then, having established the lead from existing operating conditions, the design helix angle, which applies at the design pitch circle about which the generating hob is rotated, is found as:

$$\sin\psi_2 = \frac{\pi\,n}{P_N\,L_2}.$$

Design Pitch Circle

The design pitch circle diameter is now determined using the design helix angle as:

$$d_p = \frac{n}{P_N\,\cos\psi_2}$$

and, as mentioned above, the design pitch circle is the circle about which the gear is generated using the same hob that was used for the basic design 20-tooth driven gear.

Pressure Angle

It was mentioned before that the driving gear may be considered as the basic rack or the generating hob. However, it is actually a helical gear with a slight profile curvature in the axial plane. For this reason, if the pitch circle is a variable, the pressure angle is also a variable and the pressure angle of the driven gear at its design pitch circle is found as:

$$\tan\,\phi_2 = \frac{\tan\,\phi_N}{\cos\psi_2}.$$

With the new lead and helix angle this is the angle of the sides of the hob or rack with respect to the vertical centerline in a central gear tooth position.

Base Circle

Having established the design pitch circle and its corresponding pressure angle, the diameter of the base circle of the driven gear is found as:

$$d_b = d_p\,\cos\phi.$$

Circular Pitch

The circular pitch can also be found after the design pitch circle is established as:

$$p_c = \frac{\pi\,d_p}{n}.$$

Base Circular Pitch

Knowing the circular pitch at the design pitch circle and the corresponding pressure angle, the base circular pitch is found as:

$$p_{cb} = p_c\,\cos\phi.$$

Tooth Thickness at Normal Point of Hob

Because of the spread or overlapping pitch circle and the fact that the hob is rotating about a circle on a line where the tooth thickness does not equal a space thickness as shown in Fig. 5, the tooth thickness at the normal point of the hob must be determined by trigonometric triangulation. It should be noted that the hob space thickness at the basic design pitch line is used and, because a different helix angle is involved, the hob space thickness differs from that when the basic design 20-tooth gear was generated. Here, too, is where the only difference in calculating a spread or an overlapping pitch circle driven gear comes into the picture. In the triangulation for a spread pitch circle gear, the design pitch circle radius is subtracted from the design pitch circle.

For the overlapping pitch circle gear, the basic design pitch circle is subtracted from the design pitch circle.

It can also be seen in Fig. 5 that, for the spread pitch circle gear, an upper portion of the involute curve is used and, as the number of teeth is decreased away from the basic design set, the tooth actually becomes pointed as the hob "tops" it, reducing the outside diameter of the gear. This topping action is a limiting factor for the lower number of teeth in the selection of pressure angle and diametral pitch. As the number of teeth is increased away from the basic design set, a lower portion of the involute curve is used and for the overlapping pitch circle gears the hob undercuts the tooth, and the length of actual involute profile becomes smaller and smaller. Undercut, then, is a limiting factor for the higher number of teeth.

Tooth Thickness at Design Pitch Circle

Involved in this trigonometric triangulation is the radius from the center of the

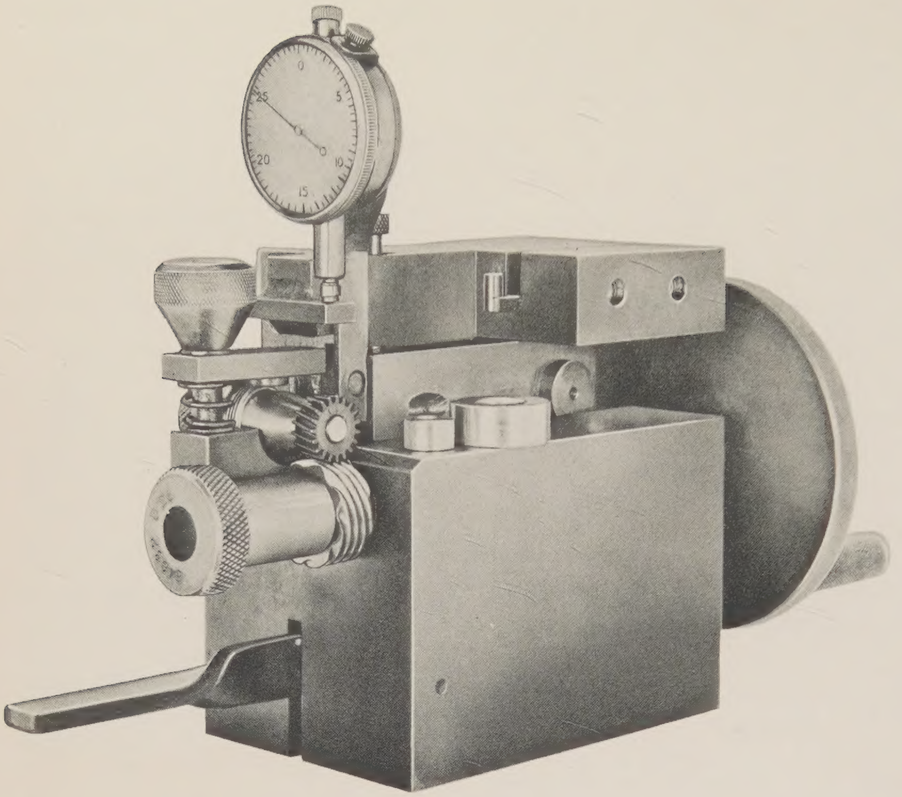

Fig. 6—This fixture is used to check the concentricity of the driven gear by rolling it with a master driving gear. The master driving gear is made of hardened steel and is accurate in every respect.

gear to the normal point of the hob r_{NH}, as well as the pressure angle at this radius ϕ_{NH} (for which the involute function is determined). The tooth thickness at the design pitch circle is then determined for zero backlash as:

$$t_o = d_p \left[\frac{t_{NH}}{2r_{NH}} + \text{Inv } \phi_{NH} - \text{Inv } \phi \right]$$

which is a standard tooth thickness equation that adds and subtracts radian measure. It is from this tooth thickness that the backlash is subtracted, as in the basic design set.

Relationships Used on the Product Drawing

Thus, the basic gear relationships have been established for the manufacture of a driven gear with different characteristics than the driven gear of the basic design set. The next question before the engineer is what to do with these relationships. Who will use what? Should all of these relationships appear on the product drawing? The designer needs all this information to make his enlarged tooth layout for analyzing the gear tooth action; the gear set-up man needs some of this information in setting up the hobbing machine; likewise the inspection department needs certain parts of this information for checking the gears.

The two examples discussed in this paper have shown how the gear relationships are all tied together mathematically. There are certain relationships that are fundamental and all of the other relationships are derivable from these fundamental relationships. Center distance, gear ratio, pressure angle, diametral pitch, and backlash are all fundamental relationships. Some of these pertain to two gears in mesh, but a product drawing is needed for each individual gear. The fundamental relationships for each individual gear are the design pitch circle, the number of teeth, the tooth thickness, pressure angle, and diametral pitch, and, in the case of a helical gear, the lead. These fundamental relationships should appear on the product drawing.

With respect to product drawing information, the specification for tooth thickness also is significant. In production, the tooth thickness is controlled by a note stating a limited backlash when the gear is rolled with a master mating gear mounted at a design center distance. This is a good method of controlling tooth thickness because there is also an allowable backlash on the mating gear and it, in turn, is checked with a master gear. If both gears then check a limited backlash, the designer can be assured of the gears running together when they are installed. Fig. 6 shows the checking fixture used in rolling the gears with a master gear to check concentricity.

However, before the gears get into production, before the checking fixtures have arrived, what is an inspector to use as a method of checking? Something else is necessary, and it is usually an *over-roll dimension*, appearing on the drawing as a reference dimension, the backlash note still standing as a controlling dimension. The inspector can calculate his own over-roll measurement, and often does; however, it is a long and tedious process which involves practically every relationship which has been discussed, and a check on the result of this calculation is certainly an aid to him. Even after the gears are in production and the checking fixture with the master gear is in use, a double check occasionally with the over-roll dimension is most gratifying to a conscientious inspector.

Summary

In summarizing, the fundamental relationships should appear on the product drawing as controlling dimensions. But, the derivable relationships should also appear on the drawing as reference dimensions.

By applying basic design concepts, each relationship in the design of these speedometer gears having different ratios can be accounted for mathematically and, in this respect, such gears are simply an example of an applied gear design that satisfies existing conditions. Other problems will have other conditions and it is not often that these conditions will be alike. However, the fact that a set of standard gears will not satisfy a set of conditions is not the end and the defeat of a gear design problem; it is only the beginning of a method of solution involving the application of basic concepts of gear tooth action.

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Glossary

For paper beginning on page 2: "A Study of Applied Gear Design: Speedometer Gears of Different Ratios in Pontiac Transmissions.

Addendum is the height by which a tooth projects beyond the pitch circle.

Backlash is the amount by which the width of a tooth space exceeds the thickness of the engaging tooth on the pitch circles.

Base circle is the circle from which involute tooth profiles are developed.

Dedendum is the depth of a tooth space below the pitch circle.

Diametral pitch of a gear is the ratio of the number of teeth to the number of inches of pitch diameter.

Helix angle is the angle of the elements of a tooth at a specified diameter with the axis of the gear. If a diameter is not specified, it is assumed to be at the design pitch circle.

Hob is a cutter used in machining gear tooth surfaces. It has teeth of rack-shaped cross section, gashed to provide cutting edges.

Involute is a curve generated by a point on a straight line that rolls upon another curve without sliding.

Lead is the distance the thread of a worm gear or threaded fastener advances in one revolution.

Pitch circle of a gear is the imaginary friction circle of the rotating disc from which the gear is designed. The pitch circles of two mating gears determine the transmission ratio of the gears.

Pitch line corresponds in the cross section of a rack to the pitch circle in the cross section of a gear. It is also the line resulting from a 90° projection of the pitch circle of a gear.

Pressure angle is the angle between the line of action of involute gear teeth of two mating gears and a common tangent to the pitch circles of the two gears.

Rack is the basis upon which standardized gear tooth systems are established. It is a bar having teeth of a simple geometrical shape. In the case of involute gears, they are straight lines whose angle corresponds to the pressure angle at the design pitch circle of a mating gear.

Over-roll dimension is a measurement taken over two pins of a known diameter and located 180° from each other, each pin nesting between two teeth.

The Air We Breathe

The Automobile Manufacturers Association has advised the editors of the availability to engineering educators of a booklet:

> "Motor Vehicles and the Air We Breathe," a talk by Charles A. Chayne, Chairman, Engineering Advisory Committee, Automobile Manufacturers Association; Vice President of Engineering, General Motors Corporation.

Mr. Chayne's talk was delivered at a luncheon of the Semi-Annual Technical Conference of the Air Pollution Control Association, in Los Angeles, on November 4, 1954.

Copies are available on request to:

Automobile Manufacturers Association
320 New Center Building
Detroit 2, Michigan

Availability of General Motors Test 20 — Gross Engine Horsepower

Members of the faculties of engineering colleges and universities may obtain a copy of the complete test procedure for determining gross engine horsepower, known as "Test 20—Gross Engine Horsepower." This test was announced in the November-December issue of the General Motors Engineering Journal and is a supplement to the fourth edition of the General Motors Engine Test Code—also available to educators. Copies of Test 20 will be sent to educators without charge upon request to:

Ralph A. Richardson,
Head

Administrative Engineering
Department

Research Laboratories Division
General Motors Corporation
Post Office Box 188
North End Station
Detroit 2, Michigan

Applied Basic Mechanics Solves a Civil Engineering Problem on Super-Elevated Curves of Proving Ground Test Track

By LOUIS C. LUNDSTROM
GM Proving Ground
Milford, Michigan

The 3.8-mile long test track at the General Motors Proving Ground, Milford, Michigan, with its two 77 per cent super-elevated curves was originally constructed of reinforced concrete. This construction lasted for over a quarter of a century; but, as in the case of all roads subjected to a heavy flow of traffic, resurfacing became necessary. The straight sections of the track presented no problem, but the curves did. Would it be possible to use conventional road paving machinery on the steep slopes or would specially designed machinery have to be used? What about the economics of the problem? These were a few of the questions that had to be answered. The solution to the problem was unique and now serves as a foundation upon which future resurfacing will be based.

The problem: Resurface an unconventional roadway with conventional machinery

The General Motors Proving Ground at Milford, Michigan, is an outdoor laboratory where all types of automotive vehicles are scientifically tested and analyzed. On any average day, a total of 40,000 miles are driven over the more than 43.4 miles of every type of road surface imaginable contained in the 3,863 acres of the Proving Ground. In addition to the level roads, there are hills with grades ranging up to 60 per cent. Each hill and each level road aid in finding the answer to how automotive vehicles perform under all types of operating conditions.

There also is a test track at the Proving Ground which is five lanes wide, 3.8 miles long, and triangular in shape with curves at the three rounded corners. The upper lanes of two curves have a maximum slope of 77 per cent, providing an equilibrium speed of 85 mph. Fig. 1 shows a view of a car traveling on the upper lane of one of the test track curves and gives an idea as to the extreme slope of the upper lane.

When this test track was constructed in 1926, reinforced concrete was used throughout. (A stiff mix of concrete is self-supporting, even on the 77 per cent slope.) As time went by, more traffic began to roll across the track and, as in normal highway use, one of the curves had to be reconditioned in 1935. Because the reinforced concrete provided good paving qualities, it was again used on the curve. Although it was used successfully it had two drawbacks: (a) it was necessary to completely close the track to all traffic for many months and (b) the large amount of hand labor made the job relatively costly. Closing of the test track seriously handicaps Proving Ground operations, as most testing schedules require some high speed operation.

The extreme degree of the sloped curves presented a problem during winter operation when conventional snowplow equipment proved useless. In an effort to clear away the snow and ice from the upper lanes, the use of large amounts of ice and snow melting chemicals became necessary. As a result, deterioration of the original concrete surface began to take place. This deterioration was accelerated during World War II when the track was used for testing heavy tanks and other combat vehicles for military purposes. The testing of military vehicles, coupled with the use of large amounts of snow and ice melting chemicals, made necessary resurfacing of the entire track. Settlement of entire slabs had, in a few cases, produced large bumps that made driving difficult.

When resurfacing of the track was undertaken in 1945, it was decided that bituminous concrete would be used as the resurfacing material. This material, composed of a densely graded aggregate and a binder of asphalt cement, has a high coefficient of friction and is capable of carrying heavy loads. The use of bituminous concrete was, therefore, ideally suited for test track purposes.

Conventional road paving machinery was used to apply bituminous concrete to the straight sections of the track and to the nearly level inside lanes of the super-elevated curves. This machinery, however, would not work on the steeply banked outside lanes of the curves. In an effort to resurface the curves, simple wooden strike-off boxes were made. After much effort, a hot bituminous mixture was spread over the upper lanes and then cross-rolled by winching a conventional pavement roller up and down the steep slopes. The resulting surface, however, was too rough for high speed operation and it became necessary to remove the bituminous mat—once again leaving the original weathered reinforced concrete surface on the upper lanes of the curves.

The original reinforced concrete surface which had provided a satisfactory road for over a quarter of a century had been subjected to conditions not usually encountered on an average highway. By 1952, the condition of the curves made resurfacing imperative.

It was realized from the start that resurfacing the curves with a bituminous concrete would be a difficult job. The experience gained from the attempt at resurfacing the curves in 1945 showed that, if a satisfactory surface was to be attained, a paving machine must be used to spread the bituminous mixture and that another method must be found for compacting the surface with a pavement roller—different from the method of winching the roller up and down the slopes. With the economics of the problem in mind, it was evident that special machinery was impractical. Conventional

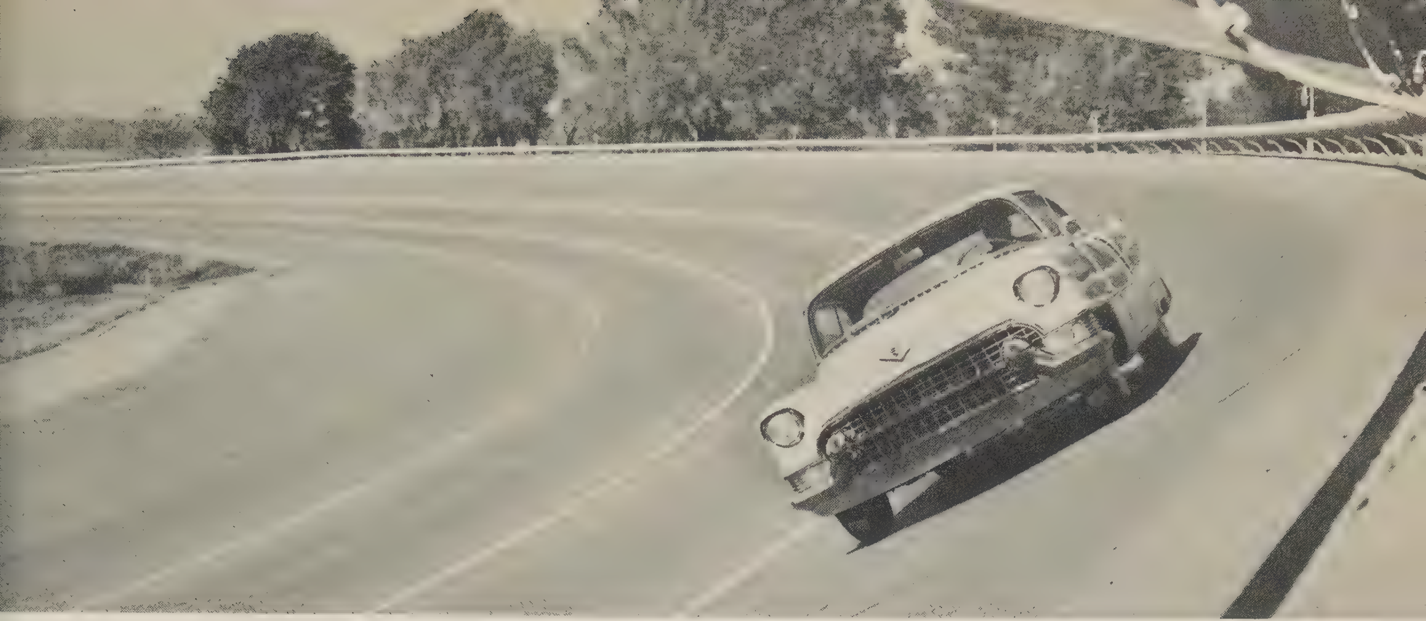
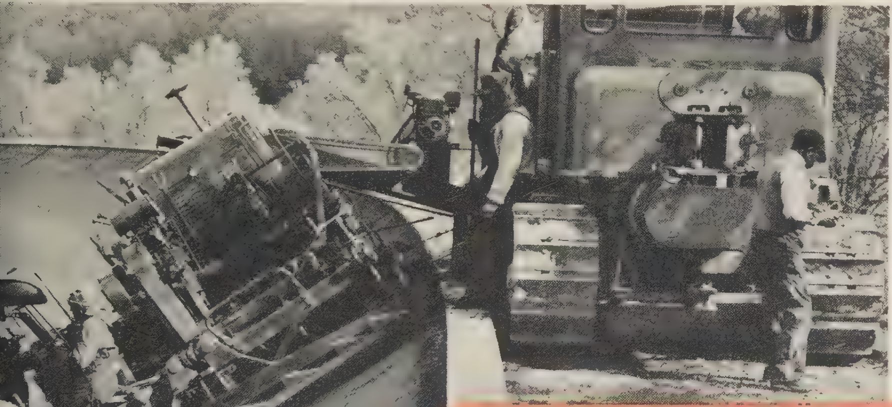


Fig. 1—The upper lanes of the two super-elevated curves of the GM Proving Ground test track at Milford, Michigan, have a maximum slope of 77 per cent which provides an equilibrium speed of 85 mph.

road paving machinery might be used if certain modifications were made to allow for satisfactory operation on the steep slopes and if a way could be found to properly support the machines when in operation. Through the application of basic mechanics, a solution was found to these problems.

Method of Support

Successful operation of bituminous paving and rolling machinery on the side slopes required special mobile supports. A truck and a tractor were



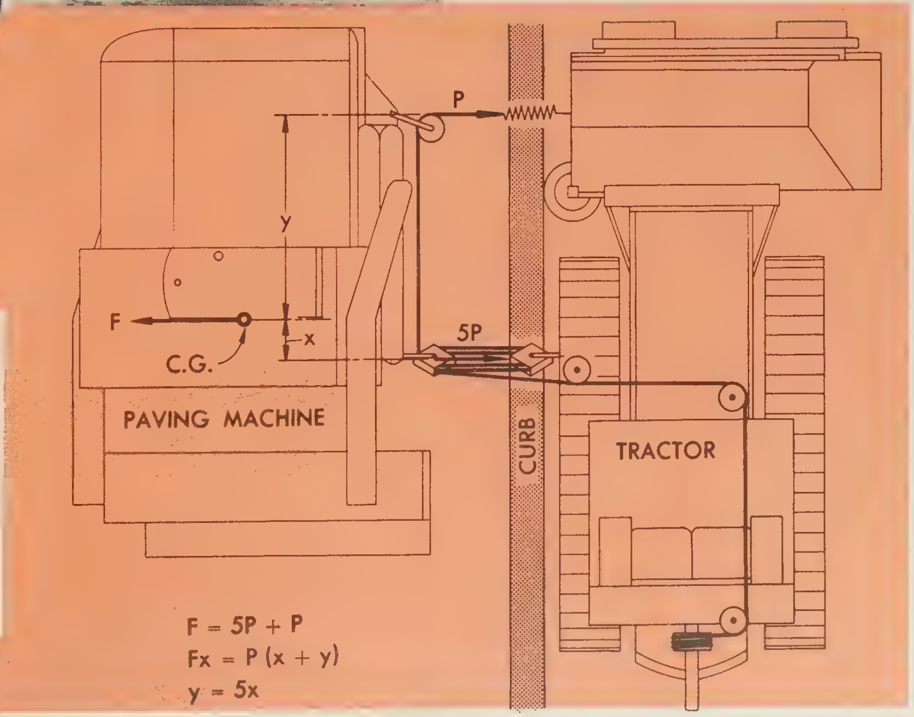
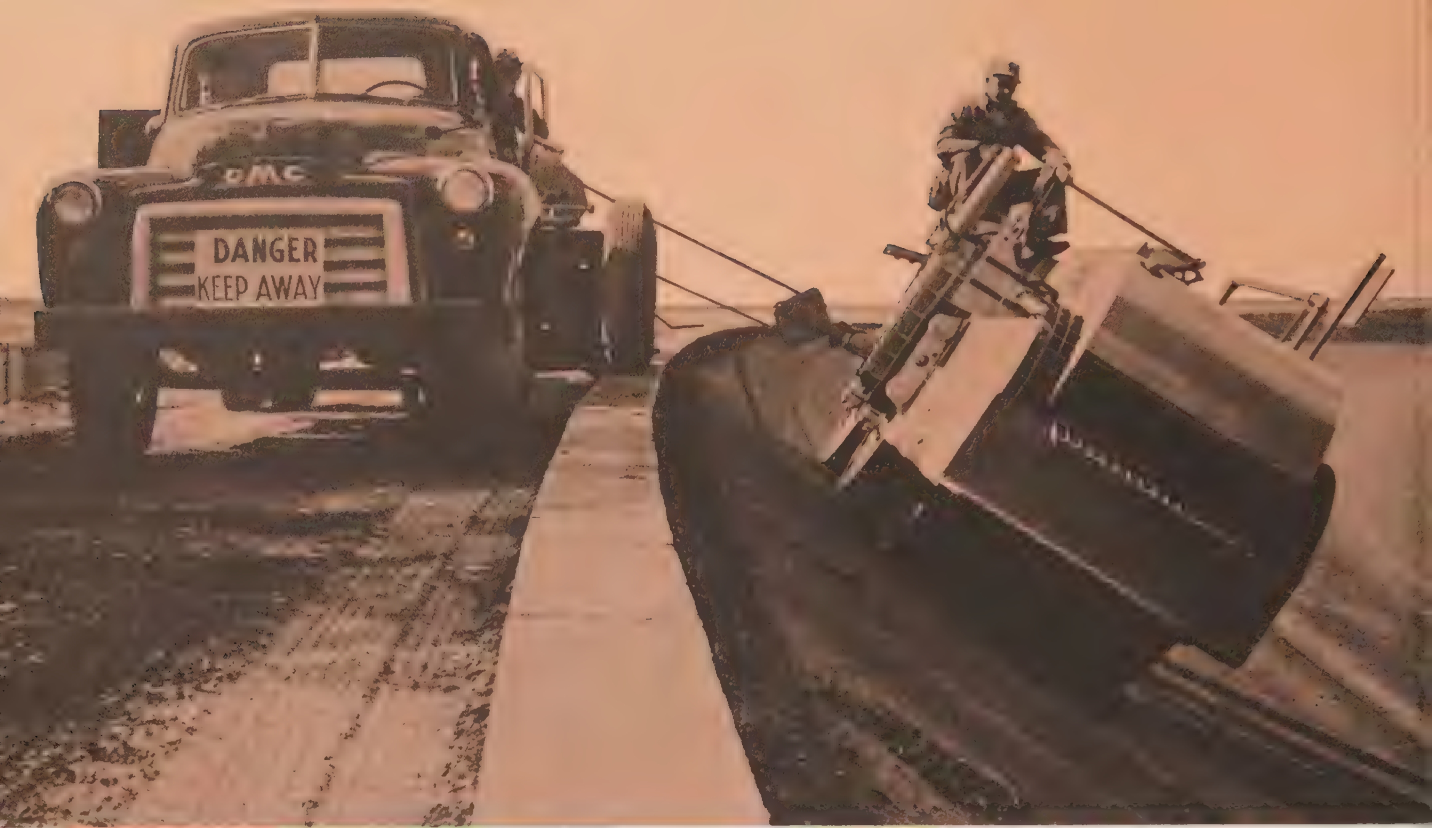


Fig. 2—The paving machine (upper) was supported on the side-slope of the two super-elevated test track curves by a line from the tractor winch which was routed laterally through the tractor to a block and tackle system connecting the tractor to the paving machine. The calculations and the force diagram (lower) determined, by the use of basic mechanics, the location for the points of attachment. A specially calibrated spring, attached to the anchor end of the cable on the front of the tractor, served to indicate the amount of side pull and aided the tractor operator in adjusting the winch to carry just the right amount of support for the paving machine.



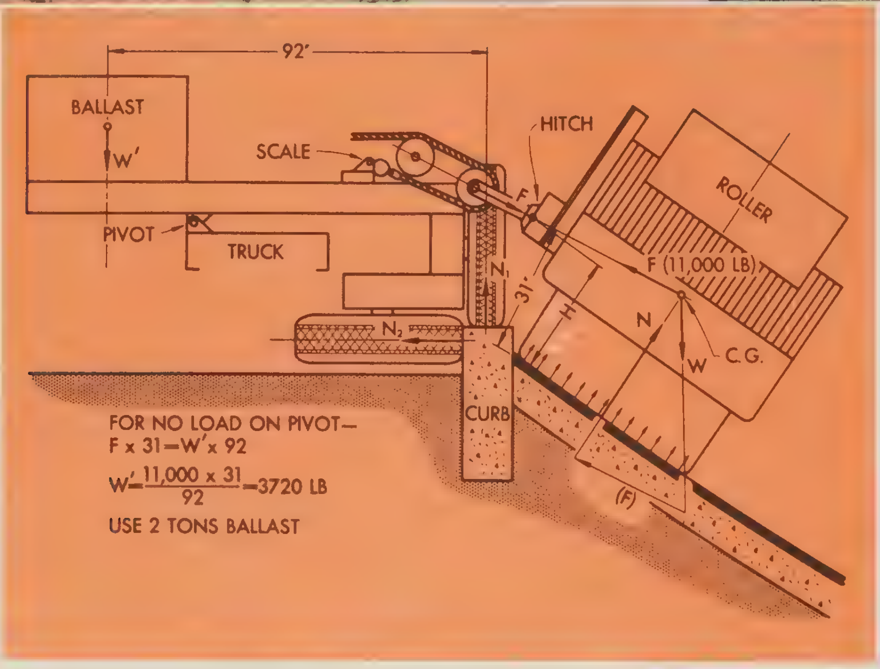


Fig. 3—The modified pavement roller (upper) was supported on the slope of the curves by a cable connected to a winch which was positioned on the flat bed of the supporting truck. The calculations (lower left) determined the amount of ballast to be placed on the far side of the truck to balance the couple produced by the cable pull *F*. The force analysis (lower right) illustrates how forces were balanced to obtain uniform compaction of the bituminous concrete. The road reaction on the roller had to be normal to the road surface and equally distributed across the roller face. This was accomplished by controlling the amount of cable pull *F* and by adjusting the hydraulically controlled hitch until its height *H* was of the amount required to pass the line of action of cable pull *F* through the roller's center of gravity.

selected as the mobile supports and these were operated on a 10-ft wide dirt roadway specially built around the top rim of the curves. To properly guide these vehicles and to absorb the large reactions, a special reinforced curbing, 1-ft wide by 3-ft deep, was placed against the top edge of the original concrete pavement slabs. This curbing, placed 2 ft into the ground, now serves as support for the guard-rail posts.

Both the tractor and truck were cable-connected to the machines they supported; but, in both cases, a complete analysis was required in order to design the necessary cable-supporting mechanisms.

Support of the Tamping-Leveling Paving Machine

One of the reasons for choosing the track-laying tractor for support was its slow-speed operation which allowed it to inch along at the same speed as the paving machine. Fig. 2 shows the arrangement of the supporting mechanism between the tractor and paving machine along with the force diagram illustrating how the forces were balanced.

A line from the tractor winch was routed laterally through the tractor to a block and tackle system which connected the tractor and the paving machine. Conventional block and tackle rigging was first tried, with the lower sheave fastened to the only available attachment near the center of the paving machine. During initial tests, it was found that the front of the loaded paving machine was too heavy and would drift down-slope; that is, the center of gravity was ahead of the support cables. As it was impractical to move the main attachment, the anchor end of the block and tackle was moved to the front of the tractor and one line was passed through an additional snatch block attached to the high-front corner of the paving machine. This forward cable produced a turning couple to balance the couple produced by the forward location of the paving machine's center of gravity.

The added side pull on the front of the tractor required the installation of a horizontal guide wheel to support and guide the tractor along the curbing. In addition, a special calibrated spring was used at the anchor end of the cable to indicate the actual amount of side pull. The tractor operator, therefore, adjusted the winch to carry just the right amount of support for the paving machine.

Support of the Three-Axle Tandem Pavement Roller

The three-axle tandem pavement roller was supported on the steep slope of the curves by a cable which was connected to a winch positioned on the flat bed of the supporting truck. Fig. 3 shows a view of the pavement roller and supporting truck in operation as well as the calculations and force analysis necessary to balance the existing forces and obtain uniform compaction of the bituminous concrete.

Side forces on the supporting truck were absorbed by two horizontal and two vertical truck tires which were free to roll along the special curbing. The four support tires were mounted on a heavy cross-frame that was pivoted along the right side of the truck frame. The floating action of this framework allowed the truck to operate on the irregular dirt roadway without seriously affecting the position of the four support tires. Two tons of weight placed on the far side of the support-wheel frame approximately balanced the couple produced by the cable pull and left the truck lightly loaded.

While the roller and the support truck were being driven side-by-side around the super-elevated curves, the cable length between the roller and truck was able to increase or decrease without changing the cable load, due to the winch being powered by a Buick Dynaflow torque converter transmission which operated at or near a stalled condition at all times. This meant that the winch engine (a conventional Buick Roadmaster engine) was constantly running under load and, therefore, delivered a relatively constant torque to the winch.

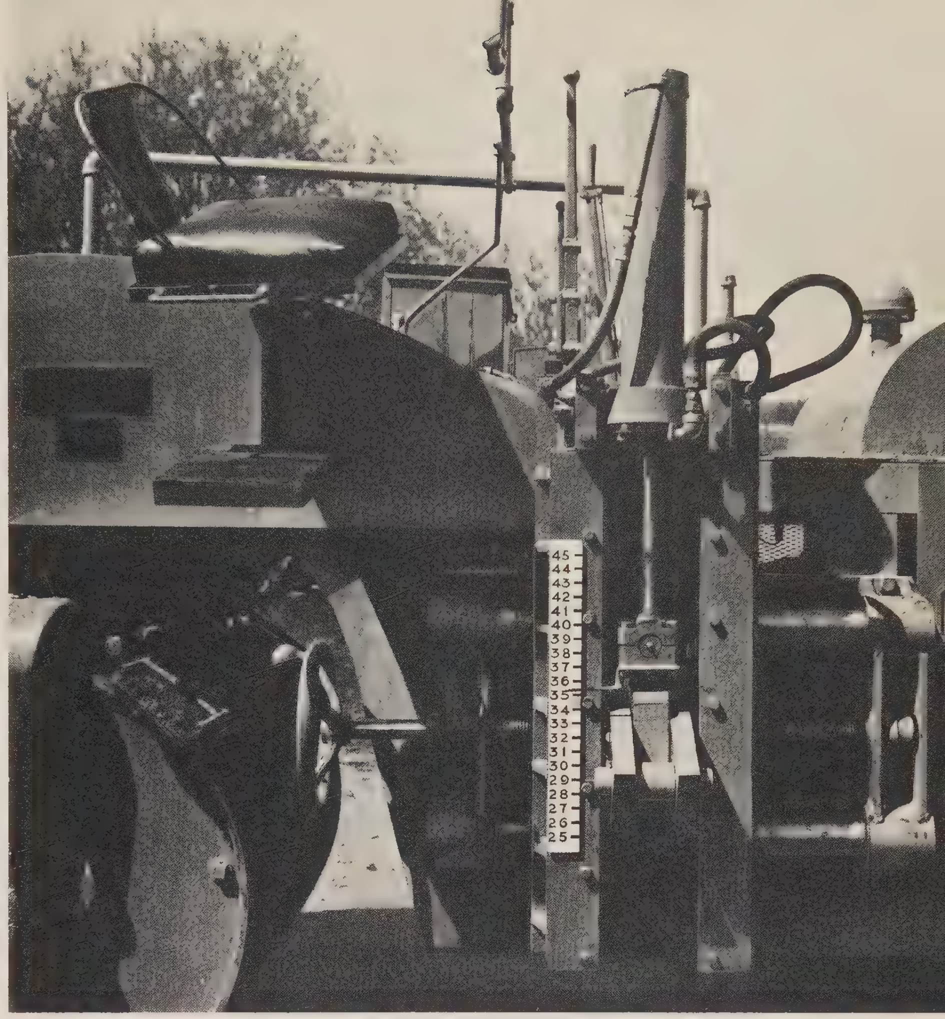


Fig. 4—A special hydraulically controlled hitch was mounted on the side of the modified pavement roller to assure that the force of the cable pull would continually pass through the center of gravity of the roller, a condition which was necessary to assure that uniform compaction of the bituminous concrete resulted. The scale on the roller was calibrated to indicate to the operator the height to which the hitch had to be raised or lowered, as the distance of the roller from the curb varied. A hand wheel for manually adjusting the fore-and-aft position of the hydraulic hitch also was provided as the location of the roller's center of gravity depended upon the amount and location of ballast on the roller.

The arrangement was such that the winch would automatically release or take in cable depending on the path along which the roller was operating. To allow continuous operation of the Dynaflow transmission at the stalled condition, special oil cooling was necessary.

To eliminate all shoving and grooving of the fresh bituminous mix, the road reaction on the roller had to be normal to the road surface and equally distributed across the roller face. In Fig. 3 it can be seen that there were only three forces which acted on the roller—the force of gravity W acting through the center of gravity, the normal reaction N, and the cable pull F. As the line of action of the force W and the line of action of the desired normal reaction N intersected at the center of gravity of the machine, equilibrium could only be obtained by having force F also pass through the center of gravity. This was accomplished

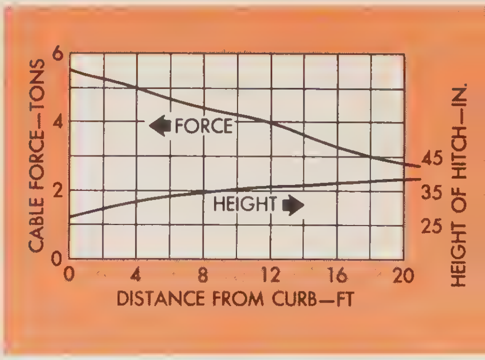
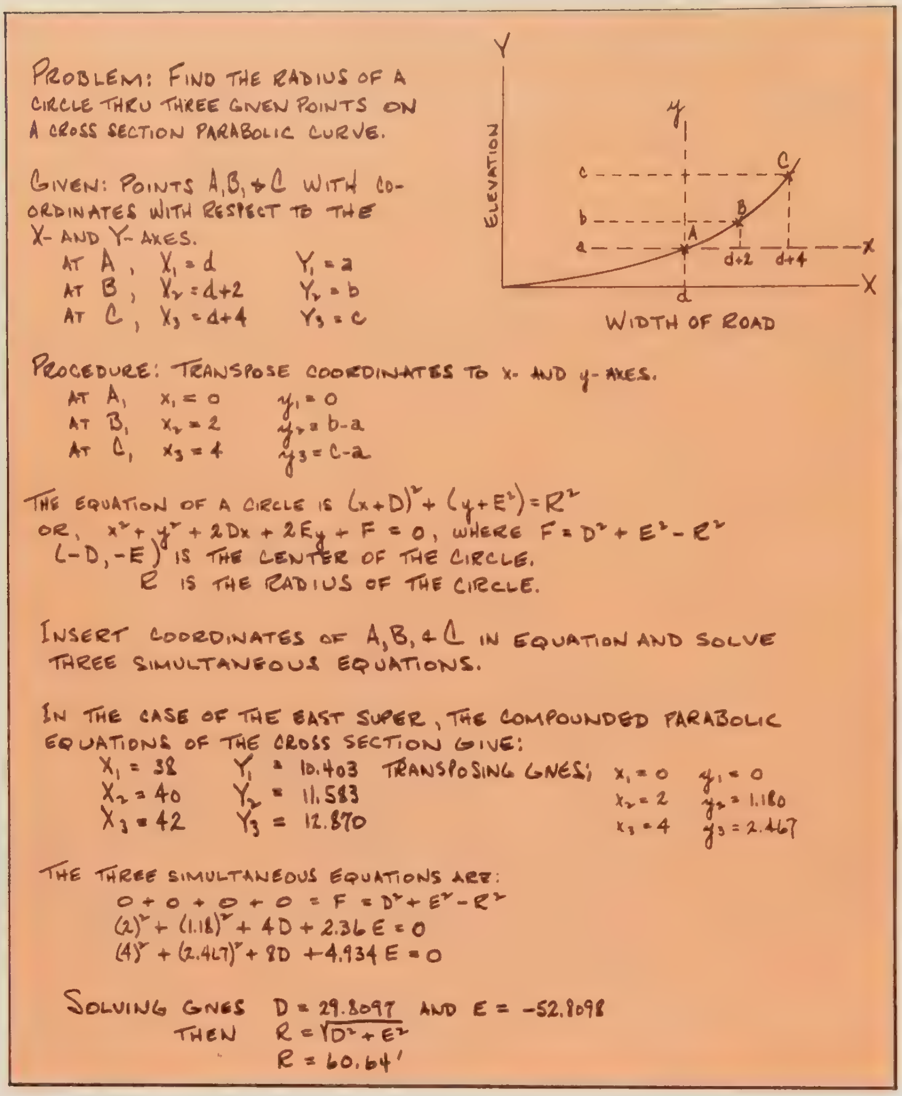


Fig. 5—To aid in maintaining a constant balance of forces necessary to assure uniform compaction of the bituminous concrete, a force analysis was made and the results plotted, which determined the required height of the hydraulic hitch with change in cable force as the distance of the roller from the curb varied.



PROBLEM: FIND THE RADIUS OF A CIRCLE THRU THREE GIVEN POINTS ON A CROSS SECTION PARABOLIC CURVE.

GIVEN: POINTS A, B, & C WITH COORDINATES WITH RESPECT TO THE X- AND Y- AXES.

AT A,	$X_1 = d$	$Y_1 = a$
AT B,	$X_2 = d+2$	$Y_2 = b$
AT C,	$X_3 = d+4$	$Y_3 = c$

PROCEDURE: TRANSPOSE COORDINATES TO x- AND y- AXES.

AT A,	$x_1 = 0$	$y_1 = 0$
AT B,	$x_2 = 2$	$y_2 = b-a$
AT C,	$x_3 = 4$	$y_3 = c-a$

THE EQUATION OF A CIRCLE IS $(x+D)^2 + (y+E^2) = R^2$

OR, $x^2 + y^2 + 2Dx + 2Ey + F = 0$, WHERE $F = D^2 + E^2 - R^2$

$(-D, -E)$ IS THE CENTER OF THE CIRCLE.

R IS THE RADIUS OF THE CIRCLE.

INSERT COORDINATES OF A, B, & C IN EQUATION AND SOLVE THREE SIMULTANEOUS EQUATIONS.

IN THE CASE OF THE EAST SUPER, THE COMPOUNDED PARABOLIC EQUATIONS OF THE CROSS SECTION GIVE:

$X_1 = 38$	$Y_1 = 10.403$	TRANSPOSING GIVES;	$x_1 = 0$	$y_1 = 0$
$X_2 = 40$	$Y_2 = 11.583$		$x_2 = 2$	$y_2 = 1.180$
$X_3 = 42$	$Y_3 = 12.870$		$x_3 = 4$	$y_3 = 2.467$

THE THREE SIMULTANEOUS EQUATIONS ARE:

$0 + 0 + 0 + 0 = F = D^2 + E^2 - R^2$

$(2)^2 + (1.18)^2 + 4D + 2.36E = 0$

$(4)^2 + (2.467)^2 + 8D + 4.934E = 0$

SOLVING GIVES $D = 29.8097$ AND $E = -52.8098$

THEN $R = \sqrt{D^2 + E^2}$

$R = 60.64'$

Table I—The calculations shown were necessary to determine the radius of circular cross section to be used on the paving machine in order to closely approximate the theoretical parabolic cross section of the super-elevated curves.

by using a special hydraulically controlled hitch mounted on the side of the roller (Fig. 4). The hitch permitted both longitudinal and vertical adjustment as required by the roller's operation on the upper and lower lanes.

Due to the parabolic cross section of the track, direct calculation of the forces on the roller would have been very complicated; therefore, the problem was solved graphically. Fig. 3 shows the very simple triangle of forces involved in the graphical solution necessary to find the required height *H* of the hitch and the roller cable force *F* as the distance of the roller from the curb varied. A plot of the values which were determined is shown in Fig. 5. During actual rolling of the pavement, the operators adjusted the winch engine throttle to obtain the required cable force and adjusted the hydraulically controlled hitch to obtain the required height *H*. A special electrical scale in the cable anchor gave a continuous indication of the actual load in the support cable.

Modification of Tamping-Leveling Paving Machine

The major requirements that had to be fulfilled by the paving machine, which spread the hot bituminous mixture to the desired depth and then compacted it with a set of tamper bars, were to provide a negative crown and a curved surface finish which would closely match that of the original parabolic cross section of the upper lanes. This meant that the bottom of the machine had to be curved.

These major requirements constituted the greatest amount of modification on the paving machine. Production paving machines are made in two halves that can be adjusted to give flat inverted *V's* necessary to produce *positive* crowned road surfaces. By increasing the clearance between the two halves and extending the range of the adjustments, the paving machine was modified to produce the high *negative* crown condition required on the super-elevated curves. Screed and tamper bars on the lower side of the production machine were made to strike off the hot mix to the desired thickness and compact it to a dense condition. As the cast iron frame of the machine was very rigid, specially machined steel shims were used to bend the screed bars to the desired curvature. Tamper bars were then machined to the same curvature.

Due to the parabolic cross section of the track, the radius of curvature varied from a minimum at the top to a maximum at the bottom. If a perfect reproduction of the original cross section was to be desired, different shims and tamper bars would be required for each lane of operation. This was impractical, and it was decided to use a circular cross section that would closely approximate the parabolic section in the high speed traffic lane. Table I shows a copy of the calculations necessary to determine the radius of the circular cross section which resulted in a basic 60-ft radius.

After determining the radius of the circular cross section, additional calculations were then made to determine what deviations would be encountered when using this 60-ft radius on other portions of the parabolic cross section. As the deviations were within practical limits, a single set of shims and tamper bars was made for the paving machine.

The deviations would have been beyond practical limits if it had not been possible to vary the amount of negative crown in the paving machine. Fig. 6 illustrates graphically how well the cross section of the paving machine with a radius of curvature of 60 ft and a negative crown of 2½ in. matched the top lane parabolic form. The same figure also illustrates how the same radius of curvature was combined with lesser amounts of negative crown to closely approximate the original parabolic cross sections of the second and third lanes.

With the maximum of 2½ in. of negative crown in the screed and with the screed shims installed, the bituminous

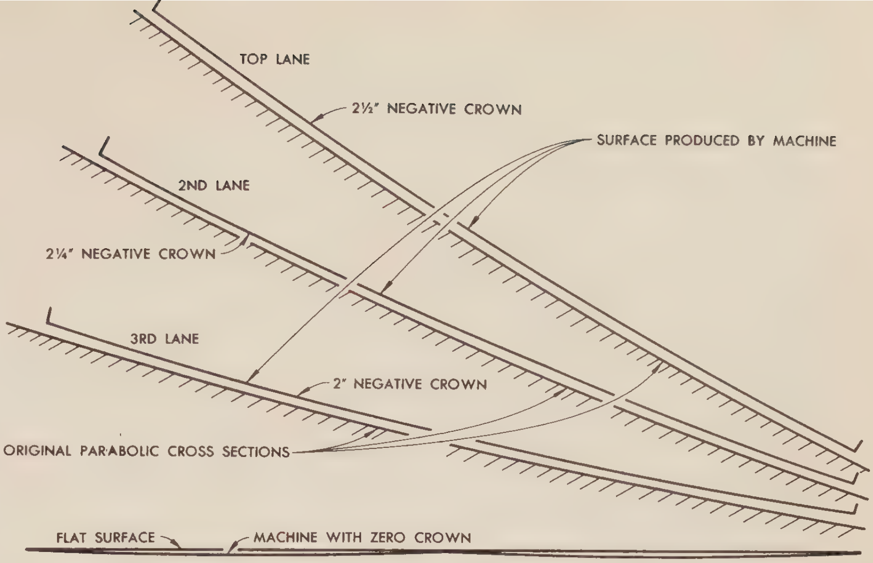


Fig. 6—To closely approximate the theoretical parabolic cross section of the top lane of the super-elevated curves, it was necessary to modify the base of the paving machine to give a 60-ft radius of curvature. To approximate the theoretical cross sections of lower lanes, the negative crown afforded by the paving machine was varied, depending on what lane of the curve was being paved. This figure shows a graphical comparison of how well the surface produced by the modified paving machine matched the original parabolic cross sections.

mat, laid by the paving machine, had a circular cross section with a radius of 60 ft.

Minor modifications that were necessary on the paving machine, in addition to the major ones listed above, were many and varied. They included wedge steps on the working platforms to permit operators to stand on the machine, a three-position tilt seat for the convenience of the driver, a guard to protect the radiator from being damaged, a lock to keep the tamper bar clutch lever from dropping out of engagement, a negative crown indicator, high-strength steel pins as replacements for cotter pins where side loading was encountered, change in the gasoline fill pipe to the high side and the outlet to the low side, new deeper oil pan for the engine, lower oil pump inlet pipe and longer oil dipstick, wedge to tilt the carburetor, and clearance for the universal joint on the tamper-bar drive shafts.

In order to control the flow of material through the machine from the forward hopper to the rear strike-off plates while it operated on the steep slopes, wedge plates and baffles were used in conjunction with the standard machine's conveyors and lateral spreader screws to keep the material from falling to the low side.

Modification of the Three-Axle Tandem Pavement Roller

A three-axle tandem pavement roller was selected for the rolling operation because it effectively leveled out any irregularities left by the paving machine. Modifications of the roller started with the use of special rollers machined to a radius of curvature of 60 ft. Thus, in the high speed lane, the most ideal condition was obtained. Fortunately, the compaction and operation of these special rollers on surfaces of smaller radii of curvature was very satisfactory.

The pavement roller was powered by a GM 2-71 Diesel engine that operated without modification. The frame, transmission, hydraulic steering, axle, and bearings of the roller were all of standard production and did not require modification.

Adjustment of the rollers was required so that all three rollers would simultaneously be in contact with the surface of the saucer-shaped track. In effect, the center roller was ¼ in. lower than the end rollers.

The fore-and-aft position of the cable-support hitch was manually adjustable so that the driver could balance the machine for the proper "feel." When compacting material adjacent to the curb, the drivers usually preferred to operate slightly off balance to the rear so that the guide (rear) roller would be several inches lower on the slope than the lead or drive roller. This enabled the drive roller to compact loosely spread material adjacent to the curb and eliminated all hand tamping.

The three-axle tandem roller was rated at 10 tons metal weight and 15 tons ballasted. To ease the load on the support cable as much as possible, the roller was used at approximately 11 tons and compaction was very satisfactory.

Delivery of the Bituminous Concrete to the Paving Machine

The hot bituminous concrete mix used for resurfacing was prepared at a mixing plant and delivered to the job site in dump trucks. Delivery of the mixture from the dump trucks to the paving machine presented a difficult problem.

Conveyors from the lower inside lanes of the track would have been too long and difficult to maneuver. It was decided, therefore, to attach a belt conveyor and hopper to the front of the support tractor. Hot bituminous mix, delivered to the site in trucks, was dumped into the hopper and then carried on a 14-ft belt across the curbing to the hopper of the paving machine. The conveyor was not operated continuously as it was desirable to move the material in batches to retain as much heat as possible. The conveyor's capacity of 120 tons per hour was not used continuously.

As the roadway behind the curbing was very narrow, the dump trucks could not turn around in the vicinity of the paving operations. This required backing the dump trucks as much as 2,400 ft. Fortunately, the back-up distance was the greatest to the transitions of the super-elevated curves, where paving operations were necessarily slow. As the supply distance decreased, normal speed of paving could be maintained.

Summary

The resurfacing of the three super-elevated curves was a project that presented problems which were largely solved by the application of engineering fundamentals. The solutions generally were not difficult when reduced to single problems. The experience and knowledge gained will be applied when similar resurfacing again becomes necessary in the future.

The success of this paving operation has also demonstrated to bituminous engineers the feasibility of applying bituminous linings to steep dam facings and canal linings by the use of paving machines. The same precision of form and rolling operation specified for the roadway would not be required but the methods of application could be the same.

How the Shell Mold Process Is Applied in Industry

The shell mold process came to Central Foundry Division several years ago and engineers found that by research and study they could favorably adapt the method to the making of high-volume castings previously made by conventional green sand practices. This research and study has continued without interruption and the number of applications for shell molding has grown steadily. The future for this new field looks increasingly fruitful as foundry engineers learn more and more about sands, binders, metal selection, flow characteristics, equipment and pattern design, and other factors which are making this thin-mold process a welcomed one in the foundry industry.

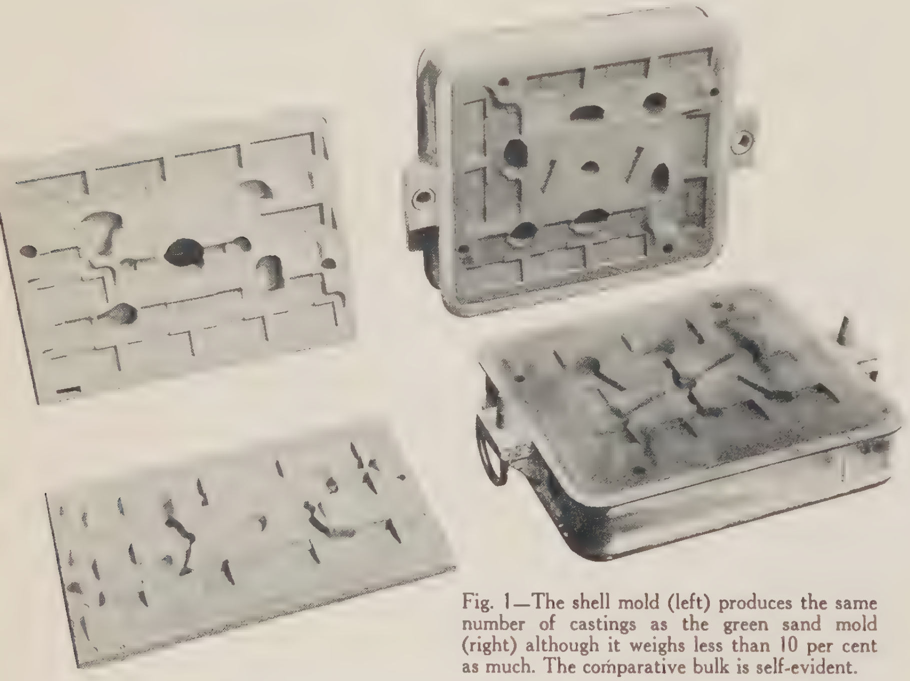


Fig. 1—The shell mold (left) produces the same number of castings as the green sand mold (right) although it weighs less than 10 per cent as much. The comparative bulk is self-evident.

The advantages of the shell mold process are rapidly being recognized in the metal-working industry. The method gets its name from the thickness of the mold, which is merely a shell of plastic-bonded sand, approximately $\frac{5}{16}$ in. thick. The process has brought about a drastic change in the appearance and weight of the mold necessary to produce a given part and has enabled foundries to supply more accurate and cleaner castings to the users, who are the ultimate beneficiaries of the attendant economies (Fig. 1). While advances in shell molding during recent years have increased the acceptance of the process by foundry engineers, the conventional green sand method remains as the most widely used means of producing castings.

The shell mold method of producing castings was developed in Germany during World War II. Instead of using the regular foundry sand mixture which has clay and water as binders, a fine dry sand mixed with phenolic resin is applied to a pattern heated to approximately 450° F. The resin melts and flows in-between the grains of sand. This feature, plus the curing on the pattern, produces a hard and smooth mold which is just as accurate as the pattern itself.

No jolting, squeezing, or ramming of a shell mold is needed as is the case in green sand molding. The corresponding requirement in the shell mold process is that the sand mixture must be dropped on a pattern face. A simple shell molding machine consists of an open-faced box which can be turned on trunnions in the center of the box. The resin and sand mixture is poured into the box to a depth of approximately 10 in. to 12 in. The pattern plate is clamped, with the pattern face down, to the open face of the box and the box is inverted. The length of time the mixture is exposed to the hot pattern determines the thickness of the shell. Usually, 15 sec to 25 sec exposure time will result in a shell $\frac{1}{4}$ in. to $\frac{5}{16}$ in. thick. The box is then reverted to its original position and the pattern with the soft shell adhering to it is removed and placed in an oven for curing. With an oven temperature of approximately 1,200° F, a curing time of 30 sec to 60 sec is required.

The pattern and the shell are then removed from the oven. The shell is stripped from the pattern and, although it is still warm, it is actually ready for use (Fig. 2). Of course, iron cannot be poured until the two halves of the shell are fastened together. This is done by placing the drag half of the shell in a gluing fixture and bonding the cope to it with a phenolic binder (Fig. 3).

At Central Foundry Division all production shells are poured in a horizontal position and without the use of back-up material. The castings are shaken out with ease after the required cooling time, due to the complete burning away of the resin bond in the areas adjacent to the casting cavities. The sand does not adhere to the casting surface as is usually the case in green sand practice.

Advantages to the Foundry

There are many characteristics of the shell mold process beneficial to the

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Division

Can the thinness of the mold bring to the foundry economy along with its accuracy?

oundry. One advantage results from the esser amount of sand which needs to be urchased and handled. Further, com- lete mechanization of the molding peration is possible for high-production uns. Also, relatively unskilled labor can e employed and working conditions are reatly improved. Since completed shell olds can be stored, stocks of molds can e built up to pour at a subsequent time. ecause the shell mold surfaces are lready clean and smooth, a minimum mount of finishing in the cleaning room s required.

hell Process Applied to Castings Difficult Mold

This process is particularly advan- ageous for quick and simple production f complicated molds, such as those re- uiring narrow and accurate passages nd sections. In some cases, it is prac- ically impossible to produce certain arts in any other way without prohib- tive machining costs.

One such part is the grey iron manual- ontrol valve body for the automatic ransmission of an amphibious, cargo- arrying military vehicle (Fig. 4). Alu- inum die castings were unsatisfactory r this particular application because of dverse expansion and wear characteris- ics. In this case, the requirement for very lose tolerances on the thickness and ocation of intricate ports was made ossible by the shell mold process. For a asting of a 5½-in. length, dimensional lerance of ± 0.003 in. to ± 0.005 in. per . would be conventional for shell castings.

The governor bodies and bushings for n automatic transmission were formerly ade of aluminum die castings, but the eel piston rings used in conjunction ith the aluminum governor body caused xcessive wear in the ring grooves (Fig.). In the past, it had not been possible

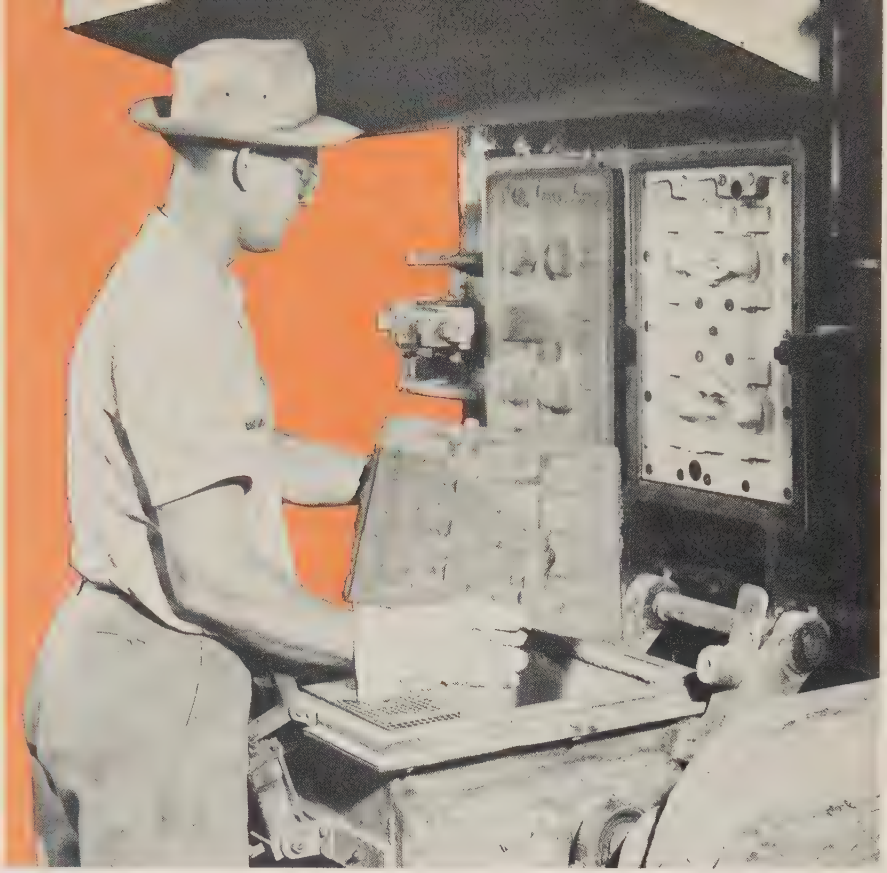
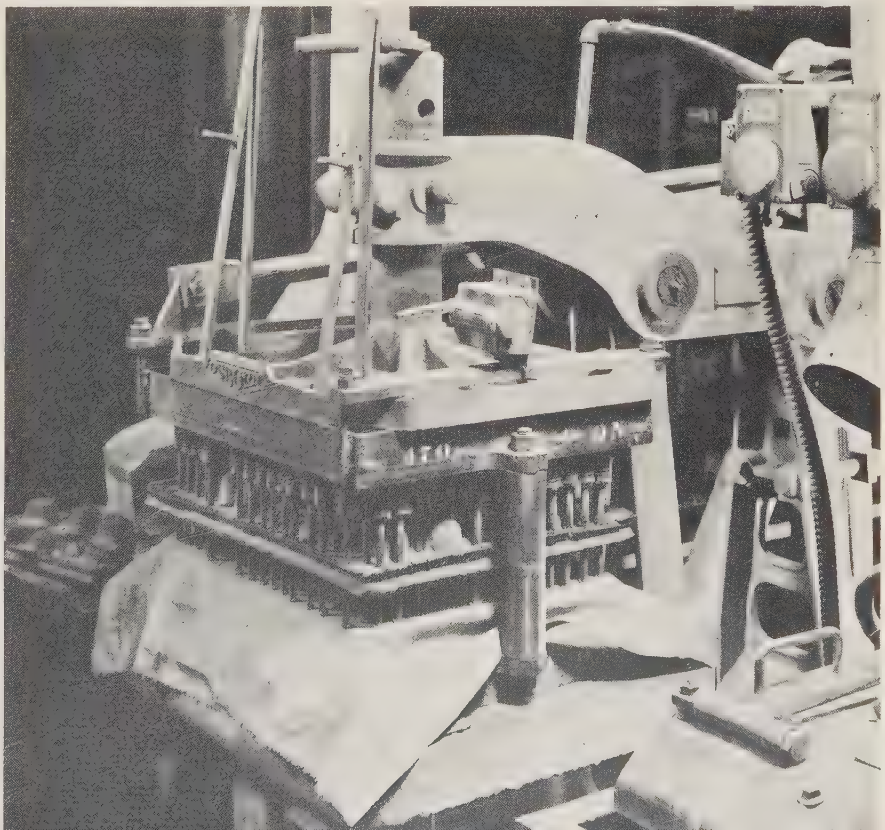


Fig. 2—The shell mold is being stripped from a fully automatic production shell-making machine. The mold, which can be handled with asbestos gloves, is ready for assembly.

Fig. 3—Here the cope and drag shells have been inserted into a gluing machine and glue previously applied around the casting cavities is being cured by residual heat from the mold-making operation. Pressure is applied by spring-loaded pins on this automatically cycling machine. Curing time for the glue is from 20 sec to 30 sec.



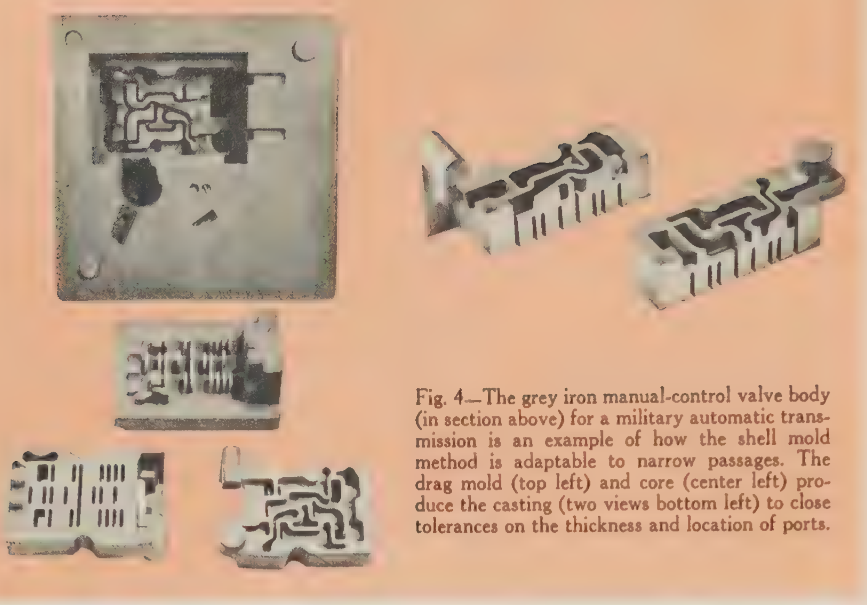


Fig. 4—The grey iron manual-control valve body (in section above) for a military automatic transmission is an example of how the shell mold method is adaptable to narrow passages. The drag mold (top left) and core (center left) produce the casting (two views bottom left) to close tolerances on the thickness and location of ports.

to cast these parts in a ferrous material because of the intricate coring involved. However, by making the cores of a mixture of phenolic resin and sand and using the shell mold process, this has now become a relatively simple job to cast in grey iron. Over 4,500 pieces of each part are being produced daily. It has been reported that excessive wear in the ring grooves has been eliminated.

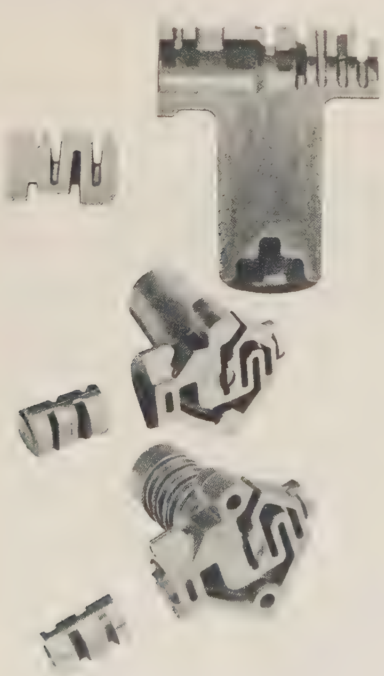


Fig. 5—The ability of shell molds to produce parts requiring intricate coring made possible a desirable change from aluminum to grey iron for this automatic transmission governor body and bushing. When aluminum die castings were used, the steel rings caused excessive groove wear. The intricacy of the grey iron casting is evident from the section views (top), completed castings (center), and the machined parts (bottom).

The nominal machining stock allowance on these two parts is 1/32 in. and in some areas it is even less. The cutaway sections of Fig. 5 illustrate the intricate ports and grooves. Of special note is that a hole is cored completely through the larger casting. The portion of the grooves cast by the core must be in perfect alignment with that made by the cope shell or mold. The minor diameter of the core is 5/16 in. and this diameter is machined to 3/8 in. by the casting user which obviously doesn't allow much of a margin for casting or machining errors.

Typical of the many shell-cast parts now being mass produced is the grey iron valve housing for automotive power steering units (Fig. 6). The housing has six internal grooves, four of which have deep extensions. Inasmuch as these grooves must be clean and accurate, it is practically impossible to produce this casting by any other method. A resin-bonded or shell core used in the process is dimensionally accurate because it is baked or cured in the core box. Furthermore, it produces a clean and smooth casting surface because of the inherent qualities of the dry resin mix. These qualities provide a tight compact core which prohibits iron penetration and results in a casting free from surface sand inclusions.

Shell Process Reduces Machining Operations

Another major advantage of the shell mold process is the reduction in the number of machining operations required to complete a part.

An example is a trigger housing or guard for the Browning automatic rifle now in production (Fig. 7). These castings are produced in ArmaSteel-GM 85M (pearlitic malleable iron) in the 197 to 241 Brinell hardness range (Table I). The dimensional tolerance and surface finish characteristics obtainable in making this part by the shell mold process eliminate the need for machining all except the wear and contact surfaces.

Most of the operations eliminated were those performed by profile milling. Although costly, these operations were necessary to facilitate handling of the gun. As a matter of fact, in this case shell castings provide an aesthetic appeal in that the blending contours can be much more pleasing to the eye and touch than are those obtainable by machining, except at impractical expense. The steel forging used for producing this part prior to World War II weighed 2¾ lb, while the ArmaSteel *green sand* casting used during this emergency weighed 2.1 lb. The current shell casting weighs only 1.12 lb as shipped from the foundry.

The recent development of a constant-friction shock absorber for Army tanks also takes advantage of the reduced-machining feature of the process for the manufacture of two of its components (Fig. 8). This shock absorber contains a three-piece shoe faced with a special brake lining. Each shoe casting has three angular flats on the pads at the center of the casting which must be cast smoothly and accurately, inasmuch as they are

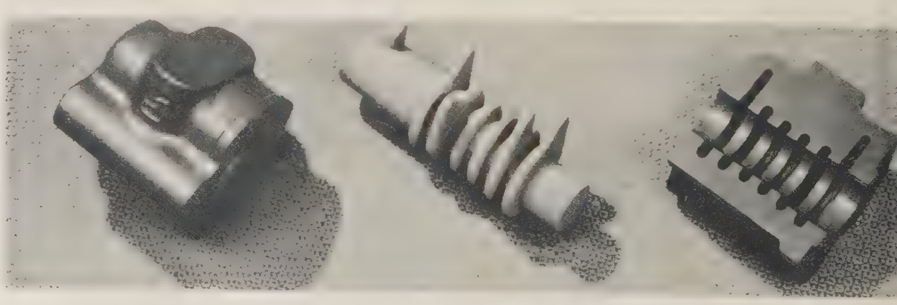
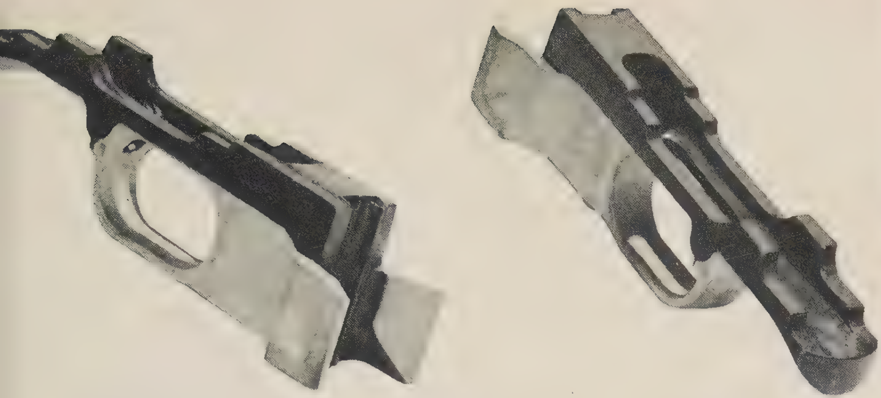
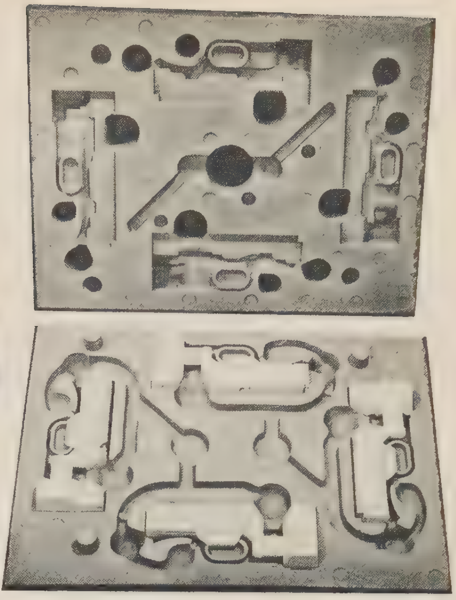


Fig. 6—The valve housing for an automotive power steering unit (left) uses a shell core (center) to produce six annular grooves, four of which have extensions. The cutaway view (right) shows the complex grooving in the part. Cores are made of resin-coated sand blown into a core box heated to about 450° F.





ig. 7—The trigger housing of the Browning automatic rifle is made from the shell mold and cores, four o a mold (right). The only machining required is on the wearing surfaces indicated by dark paint above). The light color of the cores results from a silica sand which was selected because of ease in oating. A coated sand is desirable when cores must be blown, as in this case.

	CONVENTIONAL MALLEABLE	ARMASTEEL		
	GM 11M	GM 84M	GM 85M	GM 86M
Tensile Strength (lb per sq in.)	50,000	100,000	80,000	70,000
Yield Strength (lb per sq in.)	32,500	80,000	60,000	48,000
Per Cent Elongation (in 2 in.)	10.0	2.0	3.0	4.0
Brinell Hardness Number	156 max	241-269	197-241	163-207
Brinell (mm)	4.8 min	3.7-3.9	3.9-4.3	4.2-4.7

Table I—ArmaSteel is a pearlitic malleable iron developed by Central Foundry Division and is initially produced as white cast iron. This hard, brittle material is subsequently heat-treated in controlled atmosphere furnaces to remove the massive carbides. It is air cooled from 1,650° F and tempered to a definite Brinell hardness range, which controls the percentage of combined carbon in the casting. GM 84M is produced by oil quenching and tempering and is somewhat harder and has higher mechanical properties than GM 85M and GM 86M. The latter two are air-quenched and tempered to the Brinell hardness shown. GM 85M is recommended for a part requiring a selective hardening treatment and medium mechanical properties. GM 86M is usually specified where machinability is of prime importance. All three classes of ArmaSteel produce satisfactory shell mold castings. Listed above are the minimum mechanical properties of ArmaSteel and conventional malleable iron.

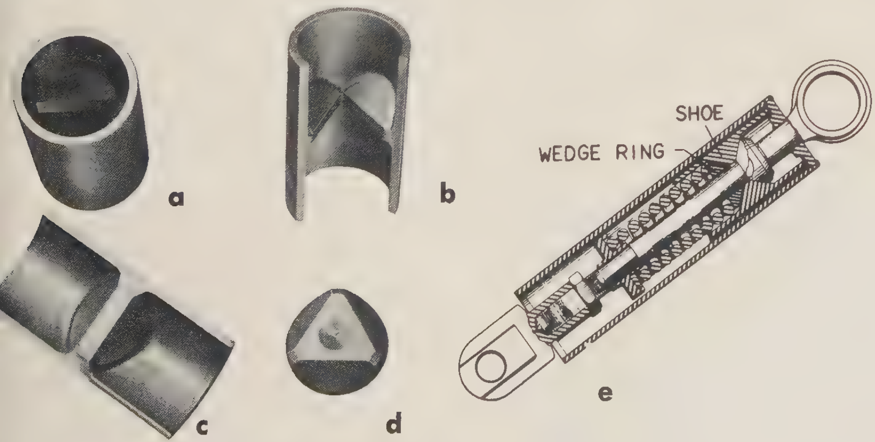
unctionally important. It would be xceedingly difficult and costly to mahine the interior of this part even though he shoe is cut into three segments after he outside diameter has been turned. Dutside of a coining operation, no other nachine work is necessary on the interior of the shell casting. Two important conributions of the shell mold process to his part are the ability to mold it withut the use of cores and the ability to lraw the pattern with a minimum of lraft on the sidewalls. In regard to draft, hell molding enables the holding of a lraft of less than one-half degree.

The other shell-molded shock aborber part is the wedge ring. Two of hese castings are used per shock aborber, being assembled inside the three hoe segments. Coining the flats plus lrilling and reaming a hole through the enter represent the only machining operations performed on the wedge-ring castings.

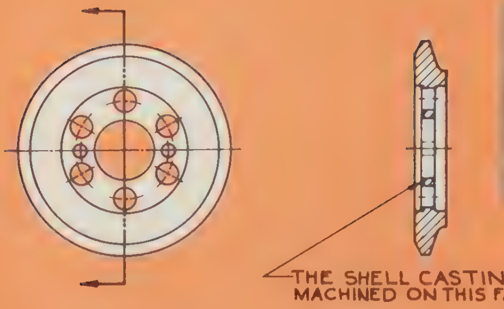
Another example of reduction of machining by making castings by the shell mold process is a grey-iron automotive harmonic balancer weight (Fig. 9). For years, this part had been made from a heavy sand casting which necessitated machining on all surfaces. With shell molding even the holes are cast and the only surface which requires machining is the mounting face. Some of the obvious advantages to the casting user in this case are:

- Less material to purchase
- Lower freight charges
- Less stock to remove in machining
- Lower capital outlay for machine tools
- Lower cutting-tool expense
- Less floor space required in the machine shop.

In general, these advantages apply to most shell-molded parts.



ig. 8—Shoe castings for a constant-friction shock absorber for military tanks are shell molded in tubular rm *a* and are trisected prior to assembly. The form of the internal angular flat is apparent from *b*, in hich one segment of the casting has been removed for illustrative purposes. (The machining is, of course, one on the OD when in tubular form before trisecting.) A machined part is shown in *c*. Two shell-molded edge ring castings, one of which is shown in *d*, expand the three shoe segments in the completed assembly The shoes are forced outward against the barrel under constant pressure produced by a spring.



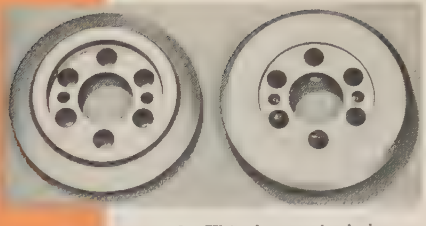


Fig. 9—This harmonic balancer weight formerly required extensive machining on all surfaces and drilling of holes. Now the only machining required is on the mounting surface and no work is required on the holes.

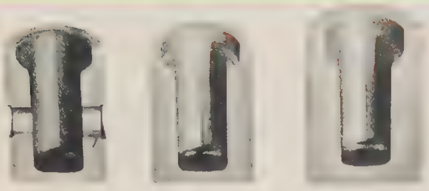


Fig. 10—The machined piston for domestic refrigerators (left) was made from the permanent mold casting (right). The shell mold casting recently developed (center) permits a two-thirds reduction in stock removal.

Shell Process Provides Better Dimensional Control

Even where machining is necessary, a shell casting offers an advantage in reducing the amount of stock to be removed. In other words, overall casting accuracy permits the use of a minimum of stock. This, of course, eliminates the need for roughing cuts on most surfaces.

An example is a small, grey-iron piston used for domestic refrigeration (Fig. 10). The finished piece weighs 0.19 lb and is made from a 0.40 lb permanent-mold casting which requires turning operations on the OD and on both ends, followed by grinding. Now a 0.26 lb shell-mold casting is proposed which requires only grinding operations in these same areas.

Another case is an automotive crankshaft sprocket formerly made from No. 1117 solid bar stock which was case-hardened after machining (Fig. 11). Although the performance of the steel piece was considered to be in a satisfactory range, the bar stock was very often on the critical list which presented procurement problems. As a solution it was decided to switch to ArmaSteel, which was readily available. This change improved the wear characteristics. Flame hardening of the teeth after machining results in a surface hardness of Rockwell 55C.

ArmaSteel lends itself to shell molding of the casting and the stock removal in machining is only a fraction compared to that required when steel bar stock was used. Formerly, it took 1.93 lb of steel for each piece while the rough shell casting weighs 1 lb. Only minor amounts of turning are required on the shell casting. The final product as produced from the shell casting is not only superior to that produced from steel bar stock but is also lower in cost.

A third example of the advantages gained from the shell mold process in controlling dimensions is a malleable iron shell casting for artillery shell booster bodies (Fig. 12). This part formerly was made of brass, frequently a critical item, and the combination of malleable iron and shell molding has provided economies without affecting function and reliability. Extensive tests by military agencies proved that malleable iron, when cadmium-plated, was satisfactory. Large quantities of three different designs of booster castings are currently being shipped to firms in the East and Midwest. Although the finished machine piece is the same in all cases, the design of the rough castings varies to suit the type of machine used.

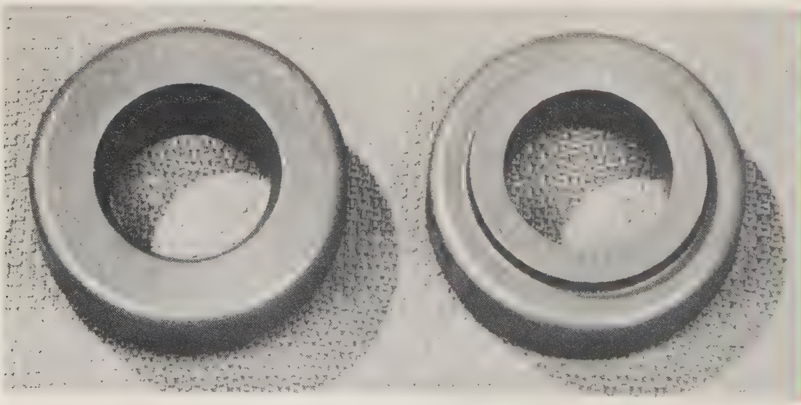
Although the improved casting accuracy obtainable in shell castings generally results in the elimination of some machining operations, extensive study of the booster body molding indicated that it would be more practical to machine it all over. The automatics and chuckers used for running brass had sufficient spindles, and fewer problems with tolerances could be foreseen. Furthermore, it was obvious that less trouble would be encountered in the cadmium plating of the piece.

Green sand castings were considered for this application but the decision to use shell castings was based on its several advantages, such as:

- Lower freight costs
- More accurate chucking
- Less machining stock (for small pieces such as this, $\frac{1}{32}$ in. to $\frac{3}{64}$ in. is usually sufficient for cutting operations, while only about 0.020 in. is required for grinding)
- Cleaner casting surface, which permits higher cutting speeds, higher production, and lower tool costs.

Conclusion

The parts described in the foregoing discussion are typical of those now in production by the shell mold process at Central Foundry Division. The experience gained and the progress which has been recorded indicate that the number of parts to which this process will be applied will increase rapidly in the future. Even now, numerous new parts are going



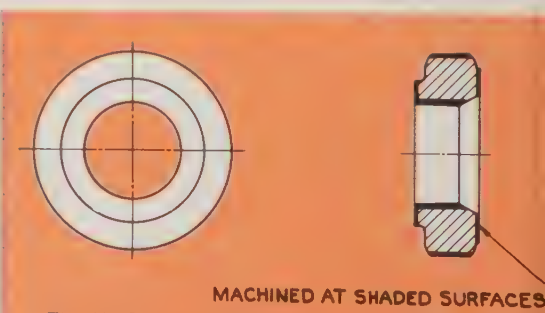


Fig. 11—This ArmaSteel shell casting of an automotive crankshaft sprocket requires minor machining as shown on the right. This part formerly was made of 1117 solid bar stock.

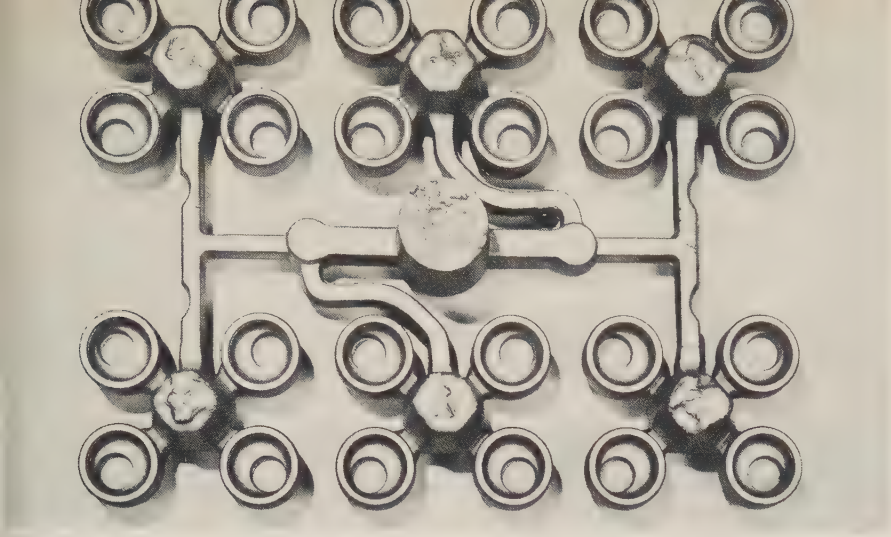
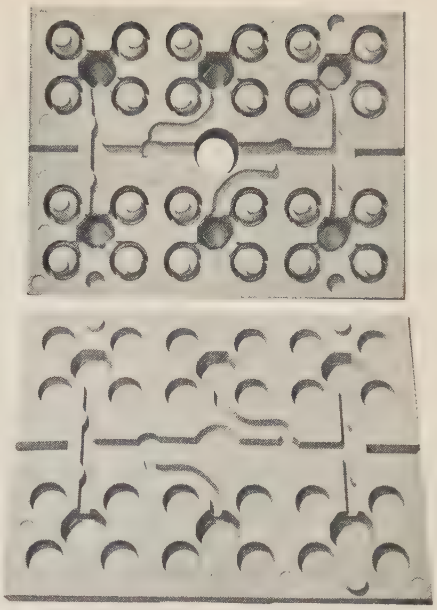
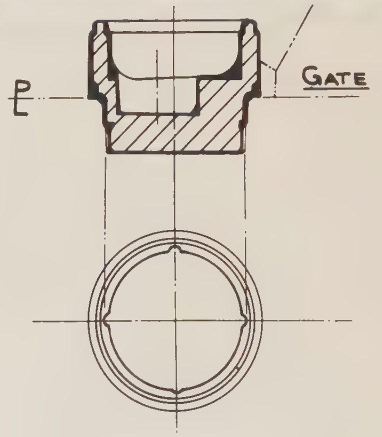


Fig. 12—Castings for this booster body for artillery shells are now made by the shell mold process. The multiple-cavity mold (top right) produces a cluster of 24 castings (above) and only minor turning is required to complete the part (bottom right). The opening through the center of the upper mold half is the sprue into which the iron is poured. From the sprue the molten iron flows through the runner system into the feeders or headers which serve as reservoirs to supply iron to the casting cavities as needed through the solidification range. The malleable iron used in this part requires that the gate be large and located at a heavy section to insure casting soundness. (Some of these pattern details are more apparent from a study of the cluster rather than of the mold.)





into production. Although the process lends itself particularly well to the production of smaller castings, size is not necessarily a limitation.

One limitation of the process is that volume production is usually a basic requirement. This is due to the higher cost of the patterns. These patterns must be machined all over to fine tolerances and finishes from close grained material which has the ability to remain stable at elevated temperatures. The required ejector or stripper pins also add to the pattern cost.

Shell castings generally are slightly more costly than conventional green sand castings, mainly because of the phenolic resin used as a mold binder. Considerable research work is underway to develop new and less expensive binders which will put shell castings in a better competitive position. Even at the present resin cost, some castings can be produced currently at a cost comparable to or lower than green sand castings. This is particularly true when cores can be eliminated.

Although the majority of castings produced today are made by the conventional or green sand method, continuing improvements in shell mold process techniques may eventually revolutionize the foundry industry. Progress during recent years rates the process as one of the greatest foundry developments of modern times. The time may come when it will be more economical to produce most small castings by this method.

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How Chemical Stability Assures Long, Attention-Free Performance of Sealed Refrigeration Systems

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Frigidaire
Division

Measure service in years; contaminants in milligrams

A high degree of reliability and long life characterize the modern refrigeration product incorporating the sealed refrigeration system. Unlike a great many other kinds of equipment in common use, the refrigerator, for example, is required to be in actual operation from 40 per cent up to 100 per cent of the time, yet it must continue to function satisfactorily for many years with no attention by the user. This long, maintenance-free operation is possible primarily because of the creation of stable chemical conditions within the system. In Frigidaire products, engineers have achieved this stability through research into the various conditions affecting the chemistry of the system. A basic understanding of these conditions has resulted in the manufacture of today's refrigeration units in which highly stable refrigerants work in combination with specially developed lubricants and motor insulation. All of these materials are sealed in for the life of the system under very careful factory processing, eliminating all deteriorating contaminants. A sound mechanical design, including a limitation of heat effects in the compressor, guarantees long, trouble-free performance.

THE sealed refrigeration system, best known for its use in the household refrigerator, makes possible a very important property for mechanical equipment—the property of long, attention-free operation. This advantage to the user has been realized only after years of research and development involving the materials, the operation of equipment, and, most important, the chemical stability of the refrigeration system.

Only a generation ago the mechanical refrigerator was a rare gadget afforded by the man of means. Performance was often unreliable and no one dreamed of guaranteeing this performance for five years. In combination with mechanical failures, there were chemical failures, too, only vaguely understood. Frequently, the household refrigerator "stuck" before it passed factory test runs. Lubricating oil sludged and varnished; compressor parts corroded and the refrigerant decomposed. Few dared to predict that it would ever become a necessity in the American home.

Today, an electric refrigerator gives more maintenance-free hours of performance than almost any other mechanism designed by man. Failure rates for operating periods of five years have been reduced to just a per cent or so of all units manufactured. Few other devices in common usage are required to meet the refrigerator's service-hour requirement over such a long period. Depending on load and ambient temperature, the average running time of the refrigerator may be from 40 per cent to 100 per cent. For most of the units this is day-in and day-out for five, ten, twenty years, or longer. There are no oil changes, no overhauls, no spare part replacements, no filter cleanings, no tuning, in fact, no attention of any kind—and this, in a mechanism with a life of 100,000 to 200,000 running hours. Compare this to everyday items such as an electric shaver, vacuum cleaner, toaster, or car. Although their average overall life is also measured in years, their actual running time is but a small percentage of this—and with varying degrees of required maintenance.

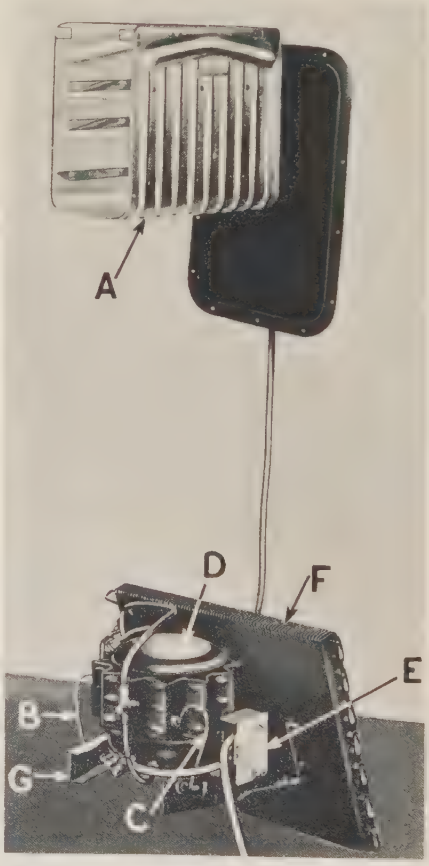


Fig. 1—A sub-assembly of the principal components of the refrigeration system is made before installation in the household refrigerator cabinet. A is the evaporator, D the compressor, and F the condenser. The capillary tube is soldered to the suction line and is not clearly visible in this photo. B and C are spring mounts, G is the base, and E is the relay controlling the compressor.

Such lengthy, attention-free performance results from sound mechanical development and studious research on materials and their effects on each other. Always, the goal has been long maintenance-free life and this requirement could be met only by creating stability of the elements of the refrigeration system, singly and in combination.

An examination of the chemistry of the system reveals how the modern refrigerator is designed and manufactured to meet this requirement.

Basic Components

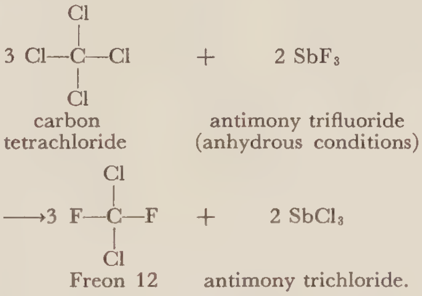
The components of the household refrigerator are simple. There are basically four mechanical components: a compressor, a capillary tube or expansion valve, a condenser, and an evaporator (Fig. 1). Temperature and electrical controls are external and enter only indirectly into the chemistry of the interior. To the four mechanical components is added the primary chemical component which is the refrigerant. Lubricant and driers or antifreeze are lso present internally but as secondary tems to insure proper functioning of the efrigerant. The compressor, working gainst the flow resistance of the capillary ube or expansion valve, compresses the efrigerant gas into a smaller volume (with consequent heat rise) and discharges it to the condenser. The condenser removes heat and liquifies the efrigerant while the capillary tube or xpansion valve controls or meters the low of this refrigerant to the evaporator. In the evaporator, the liquid refrigerant boils and carries away the latent heat of vaporation. The vaporized refrigerant ravels back to the suction side of the ompressor to complete the cycle. This appears to add up to a rather uncomplicated situation, but such is far from the ruth as evidenced by the millions of man-hours of research which were and are necessary to make the refrigerator a dependable servant in the home.

Refrigerant

The heart of a refrigeration system is he refrigerant. A story of chemical tability of refrigeration systems is a story of the chemistry of the refrigerant. Many efrigerants are available; in fact, anything which can be boiled and condensed could be termed a refrigerant under some particular set of conditions. However, for ood keeping and air conditioning, the Freon refrigerants as developed by Frigidaire and General Motors are generally the most suitable. These refrigerants are fluoro-chloro derivatives of the paraffin hydrocarbons and a lengthy series of compounds is possible. However, the two compounds accounting for the great majority of installations are Freon 12 (CCl_2F_2, dichlorodifluoromethane) and Freon 22 ($CHClF_2$, monochlorodifluoromethane). Typical physical and chemical properties of these refrigerants are listed in Table I.

Freon 12 and Freon 22 are manufactured in large quantities to practically chemically pure *CP* requirements. Boiling points and vapor pressures are closely controlled. Moisture is limited to 10 parts per million and higher boiling fluoro-chloro derivatives to no more than 0.05 per cent. No free chlorides detectable with silver nitrate are permitted. Even dissolved air is kept under 2 per cent by volume in the vapor phase. All contaminants are kept to the lowest practical level so that a highly stable compound will not become reactive due to its impurities.

There are many ways of making the Freon refrigerants, but the accepted method for Freon 12 can be shown as follows:



$$3\,\mathrm{Cl{-}\overset{Cl}{\underset{Cl}{C}}{-}Cl} + 2\,SbF_3 \longrightarrow 3\,\mathrm{F{-}\overset{Cl}{\underset{Cl}{C}}{-}F} + 2\,SbCl_3$$

carbon tetrachloride — antimony trifluoride (anhydrous conditions)

Freon 12 — antimony trichloride.

The antimony trichloride is reconverted by hydrofluoric acid to antimony trifluoride:

$$SbCl_3 + 3\,HF \longrightarrow SbF_3 + 3\,HCl.$$

In practice, the process is continuous with carbon tetrachloride and hydrofluoric acid being added constantly and Freon 12 and hydrochloric acid constantly distilled off.

The Freon refrigerants are, without question, very stable compounds compared to the ordinary organic compounds.

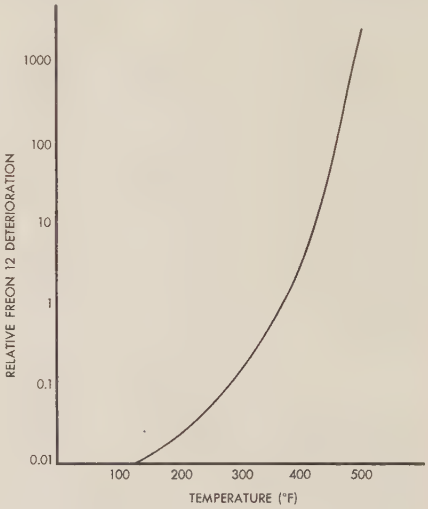


Fig. 2—Relative deterioration of Freon 12 in the presence of heat and catalysts can be indicated from test tube studies. Freon 12, strips of iron and copper, plus lubricant, were sealed in glass test tubes and exposed to various temperatures for short periods, resulting in the curve shown above. With proper care in the manufacture of the refrigeration system, deterioration of the refrigerant can be checked by controlling the effect of the catalysts, principally those in the form of salts or oxides of metals used in construction.

Properties of Freon 12 and Freon 22

	FREON 12	**FREON 22**
Chemical Formula	CCl_2F_2	$CHClF_2$
Boiling Point (°F)	—21.6	—41.4
Freezing Point (°F)	—168	—256
Critical Temperature (°F)	233.6	204.8
Critical Pressure (lb/in.^{2})	600	716
Density at 86° F (lb/cu ft)	80.7	73.4
Heat of Vaporization (Btu/lb)	71.7	100.7
Refractive Index, liq	1.285	1.252
Solubility of water in Freon (ppm at 86° F)	120	1500
Flammability	*non-combustible	*non-combustible
Toxicity	*none, Group 6	*none, Group 5a

***Underwriters' Classifications.**

able I—Engineers have catalogued the physical and chemical properties of the two main refrigerants eveloped and used by Frigidaire Division. Freon 12 is dichlorodifluoromethane (CCl_2F_2) and Freon 22 s monochlorodifluoromethane ($CHClF_2$). Both are derivatives of the paraffin hydrocarbon series of hemical compounds.

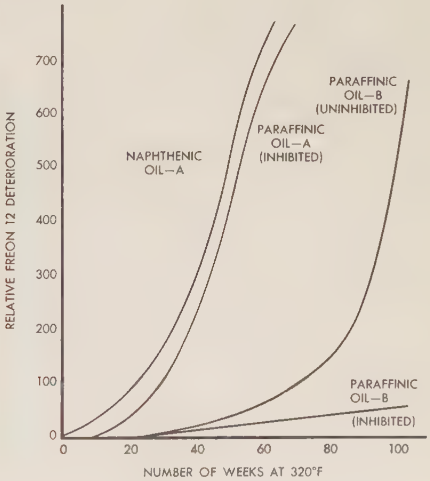


Fig. 3—Relative deterioration of Freon 12 in the presence of certain lubricants is indicated above from tests exposing the lubricants, metal catalysts, and Freon 12 in pressure glass tubes at 320° F.

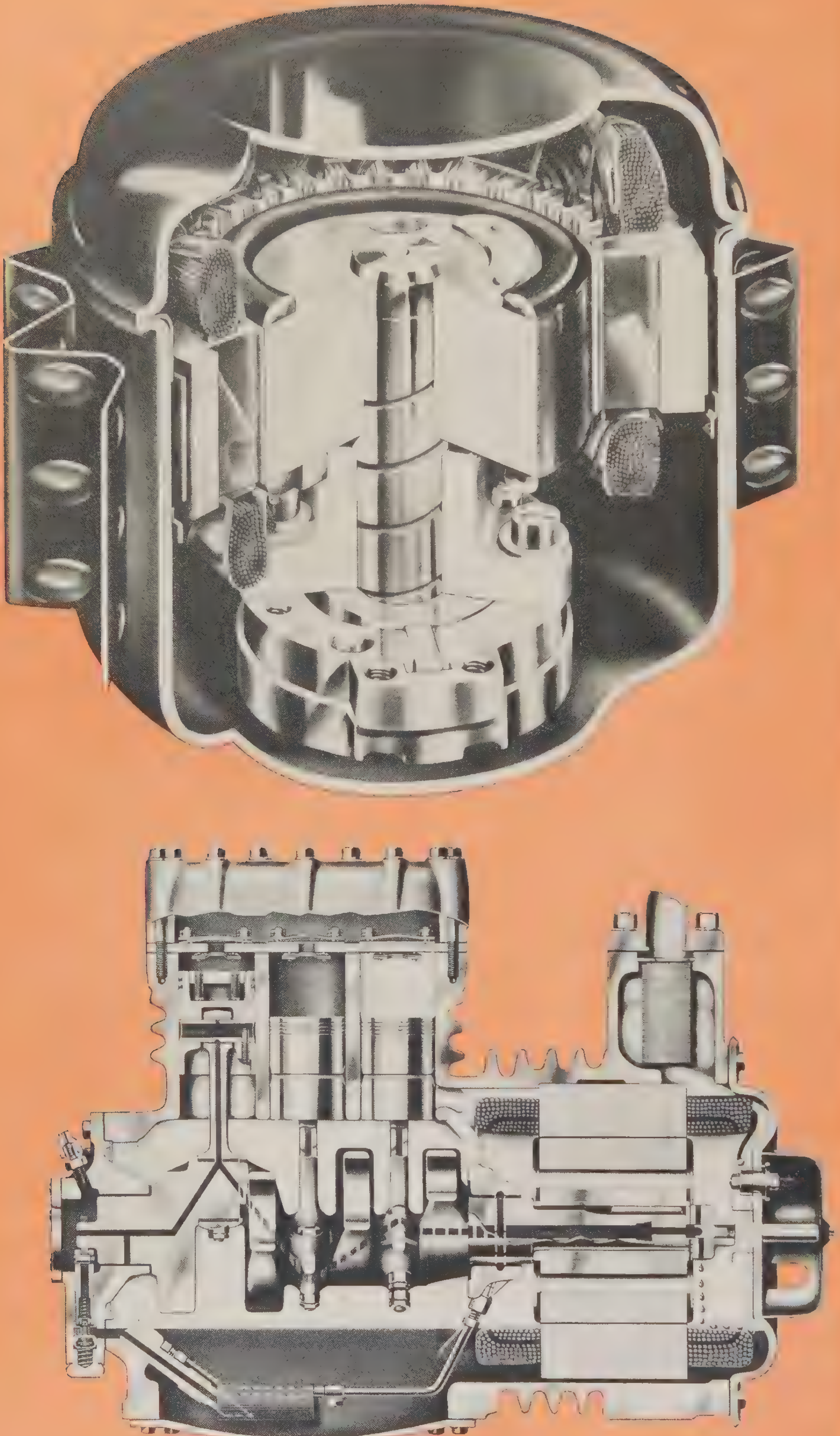


Fig. 4—In a sealed system, the refrigerant must be protected against the effects of motor arcing or short circuits as well as the materials used in the motor construction. The Frigidaire rotary, or Meter-Miser, compressor (top) is used for applications of $\frac{1}{2}$ hp or less. In this unit, the oil level when charged is slightly above the cylinder. A cross section of a sealed design for a reciprocating compressor with direct-drive motor is shown at the bottom. This unit is used for sizes through $7\frac{1}{2}$ hp.

However, everything is relative and even refrigerants can be broken down within a refrigerating system, if conditions are not right. This does not mean that extremes need exist, but the refrigerator is a long-life mechanism and even a milligram a week of decomposition or reaction product may stop the mechanism far short of its expected service. When system conditions are not right, the products of decomposition can be hydrochloric acid or hydrofluoric acid, copper plating, polymerization, gumming or tarring of the lubricant, non-condensible gases, water, metal salts, corrosive organic acids, aldehydes, and a host of similar compounds.

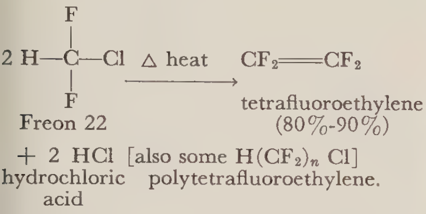
Heat Effects

One of the deteriorating forces acting on the refrigerant is the heat generated in the compressor. Heat of compression, frictional heat of moving parts, and the heat equivalent of the electrical power input all combine in an attempt to destroy the Freon molecule. For each 18° F temperature rise, this destructive effect is approximately doubled; consequently, within permissible limits, every attempt is made to design a cool-running compressor.

One of the problems which has to be met in such a design, however, is the trend toward high power and high capacity in small packages—a trend which exists in refrigeration as it does in other fields. The modern kitchen allots less and less space for the refrigerator, yet today's homemaker demands more and more space within this refrigerator. Much of the space gain has been taken at the expense of the motor compartment, thus resulting in higher compressor temperatures. The window air conditioner must be designed small enough to cover with drapes inside and not show too much on the outside. The complete home air conditioner rarely finds quarters in a spacious basement, but is confined to an ever smaller utility room or a closet. The modern car gets ever roomier for the occupants, the trunk bigger, the lines lower—all at the expense of the motor compartment. With hardly room for motor and accessories, a 2-ton to 3-ton capacity air conditioner must also be squeezed in under the hood. All this means higher and higher heat in smaller and smaller compressors.

On short term *pure* heat exposure (without the aid of catalytic agents), the

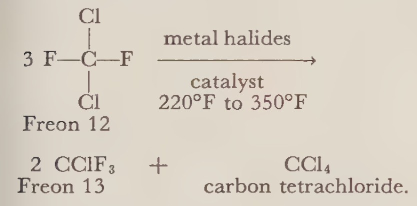
Freon refrigerants show no significant decomposition. For instance, to get at least an 80 per cent to 90 per cent yield of decomposition products the noncatalytic pyrolysis of Freon 22 must be conducted at 1,200° F:



$$2\ \mathrm{HCF_2Cl}\ \xrightarrow{\triangle\ \text{heat}}\ \mathrm{CF_2{=}CF_2} + 2\ \mathrm{HCl}\ [\text{also some } \mathrm{H(CF_2)_n\,Cl}]$$

Freon 22; tetrafluoroethylene (80%-90%); hydrochloric acid; polytetrafluoroethylene.

However, with catalysts (and iron or copper or their oxides or salts can be such), the required temperature for pyrolysis is dropped substantially and trace reaction may begin at 250° F or even 200° F. The salts of the metals are much more potent than the metals themselves. Also, with every additional bit of decomposition, more hydrochloric acid is formed to further react and form more catalytic metal salts. Not all the refrigerant reactions are necessarily destructive. Molecular rearrangements can occur and yield compounds which, though not corrosive, still impede performance. One of these reactions is *disproportionation:*



$$3\ \mathrm{CCl_2F_2}\ \xrightarrow[\text{catalyst}\ 220°\text{F to }350°\text{F}]{\text{metal halides}}\ 2\ \mathrm{CClF_3} + \mathrm{CCl_4}$$

Freon 12; Freon 13; carbon tetrachloride.

The resultant Freon 13 ($CClF_3$, monochlorotrifluoromethane) has a boiling point of −115° F while the carbon tetrachloride in the reaction is only 1/1500 as stable as Freon 12 and can quickly decompose further. Another reaction, resulting in polymerization and often gumming because of heat and catalysts, is *dehalogenation:*

$$6\ \mathrm{CCl_2F_2}\ \xrightarrow[\text{catalyst}]{\triangle\ \text{heat}}\ 3\ \mathrm{CF_2{=}CF_2} + 4\ \mathrm{FeCl_3}$$

Freon 12; tetrafluoroethylene; ferric chloride.

If these examples of disproportionation and dehalogenation reactions are taken, together with all other possible reactions in the presence of heat and metal catalysts, a decomposition curve can be plotted as shown in Fig. 2. This indicates definitely that the Freon refrigerants, while resisting pure heat decomposition to a 1,000° F or 1,200° F temperature, are seriously affected at temperatures as low as 450° F when catalysts are present. To a minor but measureable extent these catalysts can be the iron, copper, and aluminum used for refrigerator construction. To a greater degree, these catalysts are the metal salts or oxides of these metals. These salts can form initially if care is not used in processing during manufacture and assembly.

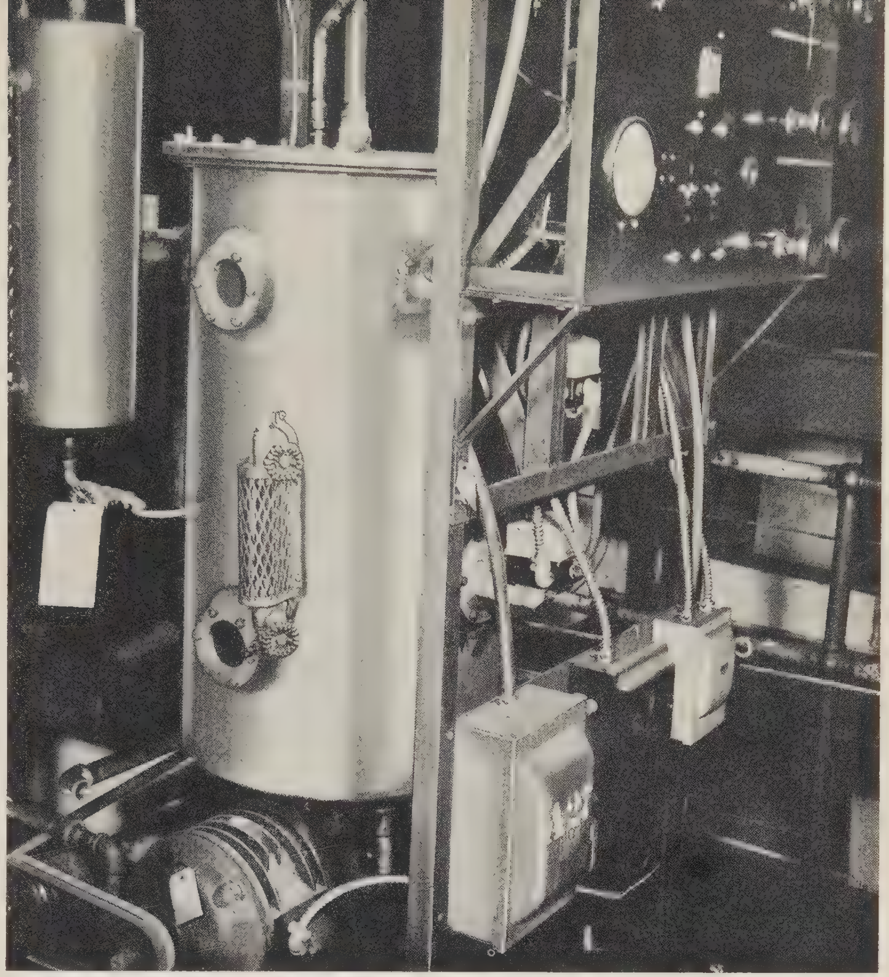


Fig. 5—One of the sources of contamination to the refrigeration system is air dissolved in the lubricant. Eliminating this contamination is accomplished during manufacture of compressors by spraying lubricant into the top of this oil deaerator. The lubricant settles to the bottom while the air is flashed off and pulled away by a high vacuum. The oil is then kept from all air contact and delivered through pipe lines and automatic weight charging equipment to the refrigerating units.

Lubricants

The lubricant used in a Frigidaire refrigerator is sealed inside for the life of the system—and to great degree determines the life of that system. The major proportion of the lubricant stays within the compressor, but small amounts constantly circulate with the refrigerant. Refrigerant, to varying degrees, is always dissolved in the lubricant and it is this solution which lubricates the compressor bearings. The physical properties of the lubricant are such that adequate viscosity and body are always available to the bearings in the hot compressor. Likewise, solubility in the refrigerant and resultant viscosity in the cold capillary or expansion valve and evaporator are such that blocking cannot occur because of molasses-like oil or precipitated wax. Chemically, the lubricant is selected for stability because the same deteriorating forces attack it as those that affect the refrigerant. Further, the lubricant is selected to have the minimum possible reaction with the refrigerant and the other elements of the system.

There are extreme differences in the behavior of various available lubricants within refrigeration systems. The best show little reaction with the Freon refrigerants and little change in themselves on reasonable exposure. The worst can react with or catalyze almost total destruction of the refrigerant. In the

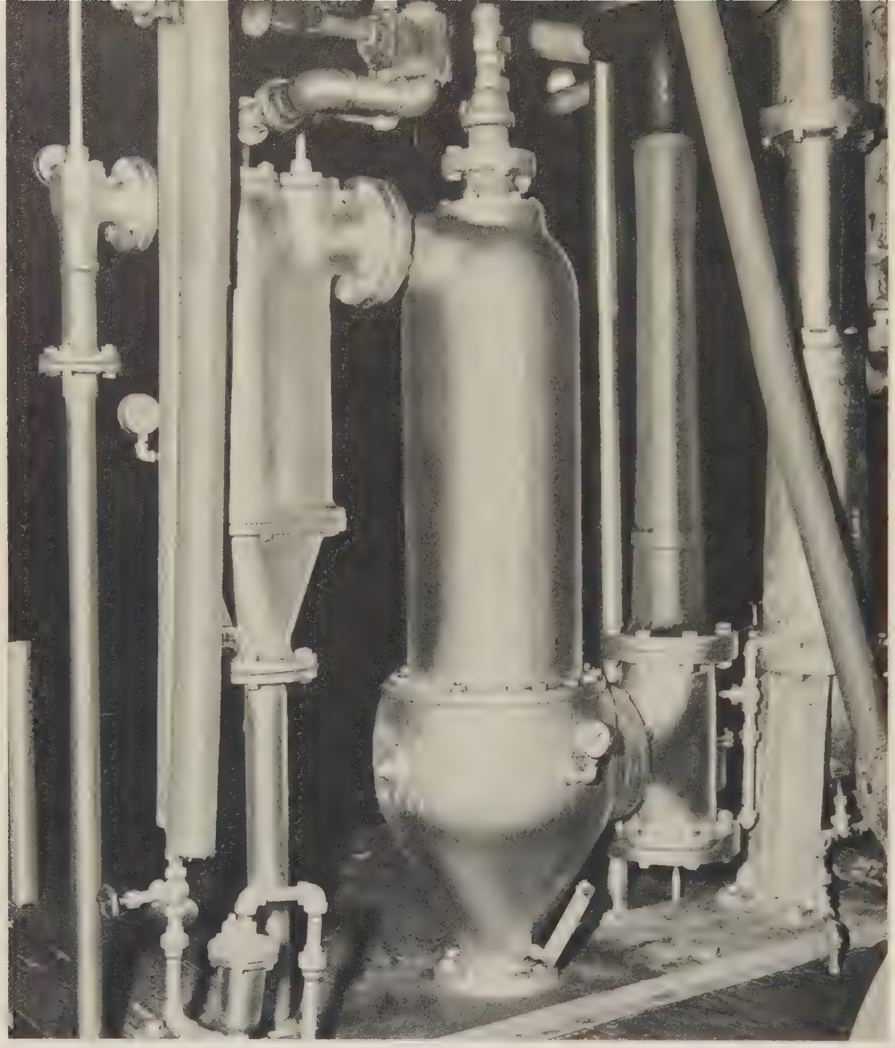


Fig. 6—Multistage steam ejectors constitute part of a system used to pull vacuum in sufficient quantity for factory operations at Frigidaire. The entire system extends three stories high and connects to oil deaerators, dehydration ovens, and charging boards.

compressor, with heat and catalysts the products of reaction with refrigerant are acids and resinous or even tarry compounds:

$$\underset{\text{Freon 12}}{CCl_2F_2} + \underset{\text{lubricant}}{CH_2—CH_2—CH_2 \ldots\ldots CH_3} \xrightarrow[\text{catalyst}]{\triangle\text{ heat}} \underset{\substack{\text{hydrochloric}\\\text{acid}}}{HCl} + \underset{\substack{\text{hydrofluoric}\\\text{acid}}}{HF} + \text{tar.}$$

In the above equation the lubricant is simply represented by a paraffin molecule but, in actuality, the lubricant is a mixture of thousands of compounds. The most probable reactants with the refrigerant would be unsaturated groups, unstable ring structures, molecules containing sulphur, nitrogen, phosphorous, acids, and other oxygen compounds. Fig. 3 shows the relative reactivity of typical refrigeration lubricants with Freon 12.

Refining and inhibitors all combine to give these differences. The selection and development of a refrigeration lubricant is more complex than the evaluation of a refrigerant. The refrigerant is one compound of very definite constitution and reproducible physical and chemical properties. Once determined, these can be written down and manufacturers must follow the specifications. A lubricant, however, consists of thousands of compounds—so complex that to date no lubricant has been completely analyzed for constitution. There are many ways of refining them. In consequence, to select the best lubricant requires thousands of tests, particularly when a refining method or inhibitor is to be evaluated.

From many laboratory and refrigerator tests, it has been determined that, generally, the paraffin-type oils are more stable in the total system than naphthene-type oils. Yet, this cannot be a sweeping generalization because some paraffinic oils, apparently of comparable analysis as the best paraffinic oils, will test no better or even worse than the average naphthenic oils. This simply confirms that n enough is known about the exact const tution of oils to pick out all of the good bad compounds. Oxygen-containin compounds already in the oil or forme from air or motor insulation can increas *varnishing* and copper plating severely. I fact, any generally reactive compound usually found to be detrimental to th refrigeration system. This imposes severe limitation on the selection lubricity, extreme pressure, or anti-wea agents. Any active compounds left in th oil from refining or added for a particula purpose must have only specific an known reactions which do not creat resultant compounds harmful to th system.

Refining methods for refrigeratio lubricants include ordinary distillation solvent refining, vacuum distillation, aci treatment, and special clay sorptio processes. All of these procedures ar strongly affected by the temperature the operation and all of these procedure can be widely modified to improve th lubricant. However, the basic problem to find the required refining procedur which is also economical enough to b industrially useful. Simply refining to th nth degree—as in the obtaining of white oil—does not necessarily yield good refrigeration lubricant.

Motor Insulation

The electric motor for both rotary- an direct-drive reciprocating compressors sealed within the compressor shell and exposed to both lubricant and refrigeran as shown in Fig. 4. The stator of th motor contains insulating materials suc as the phenolic plastic wire coating, th paper slot and coil insulators, and th cotton coil tying string, in addition t the cotton lead-wire insulation. All thes are organic materials exposed to th same heat and catalyst effects as th Freon refrigerant and lubricant and the are further subjected to the extractiv and reactive effects of these material The paper and cotton used are speciall processed materials to reduce, to a absolute minimum, any organic or in organic extractables into the Freon or o and to give the maximum possibl resistance to heat. However, with suff cient temperature, and particularl catalyzed by any traces of HCl and H which may be formed, the cotton an paper cellulose can break down int numerous undesirable compounds:

$$\underset{\text{cellulose}}{(C_6H_{10}O_5)_n} \xrightarrow[\text{catalysts}]{\triangle\ \text{heat}} \underset{\text{carbon monoxide}}{CO}$$

$$\underset{\text{methane}}{CH_4} + \underset{\text{hydrogen}}{H_2} + \underset{\text{nitrogen}}{N_2}$$

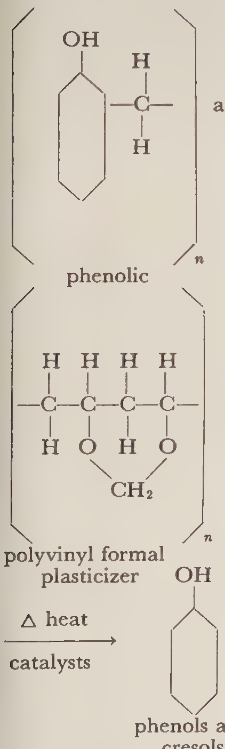
$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{organic alcohols}}{CH_3OH} + \underset{\text{organic acids}}{CH_3COOH}$$

$$\underset{\text{water}}{H_2O} + \underset{\text{ketones}}{CH_3COCH_3} + \underset{\text{aldehydes}}{CH_2O}$$

$$\underset{\text{ammonia compounds}}{NH_3} + \underset{\text{cyclic compounds}}{C_6H_5CH_3} + \text{tars and charcoal.}$$

Once even small quantities of these mpounds are formed they are free to act further in the system and cause mage, even if the stator itself is not gnificantly affected. There are at least g of cellulose, even in the smallest ator, and enough water alone could be rolyzed out to freeze-block a capillary be or expansion valve.

The phenolic coating has also been eveloped to be extraction- and heat- sistant, but once design temperature nits are exceeded it, too, is a source of rolytic products within the system:



$$+ \underset{\text{aldehydes}}{-CH_2O} + \underset{\text{acids}}{HCOOH}$$

$$+ \underset{\text{carbon monoxide}}{CO} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water.}}{H_2O}$$

mperature limits, therefore, must be curately known and not exceeded, for y significant quantity of these com- unds can shorten system life. The trace amounts of these substances formed at lower temperatures at long exposures must be combated by inhibitors and drier-sorbers. The rate and degree of these reactions are affected to a surprising degree by the nature of the lubricant in the system.

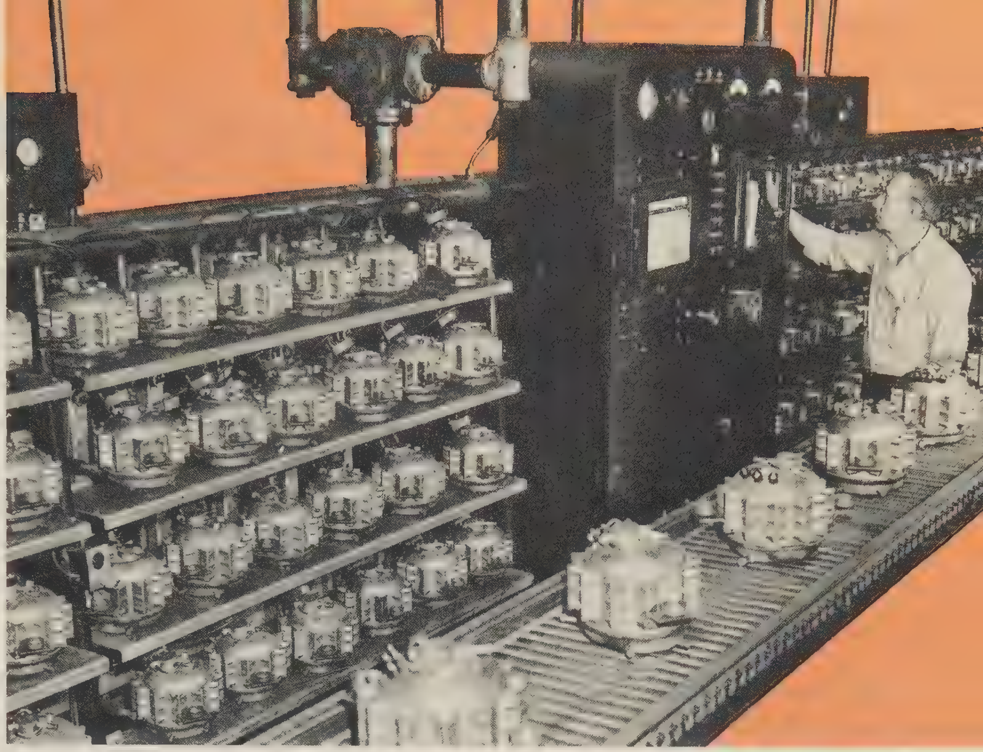


Fig. 7—Rotary compressors are dehydrated by connecting them to a high vacuum manifold (top of rack). The compressors are then heated by imposing a low voltage current on the stator of each motor. The current is insufficient to turn the compressor but brings it up to the desired temperature of 250° F.

The function of the insulation is to prevent arcs and short circuits. Should there be a failure of this, the resulting electrical arcing or short circuiting can quickly break the Freon refrigerant into its components which generally quickly react to form acids:

$$\underset{\text{Freon 12}}{CCl_2F_2} + \text{arc} \longrightarrow \underset{\text{carbon}}{C} + \underset{\text{fluorine}}{2F} + \underset{\text{chlorine}}{2\,Cl}$$

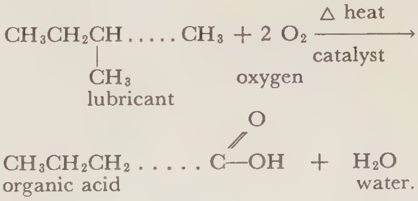
$$\xrightarrow[\text{cellulose}]{H_2O,\ \text{oil}} \underset{\text{hydrofluoric acid}}{2\,HF} + \underset{\text{hydrochloric acid.}}{2\,HCl}$$

The acids can go on further to break down more cellulose, cause corrosion, and copper plating. To insure that such reactions cannot happen, all wiring in the stators is tested at 2,200v. Any faulty stators are thus eliminated before being assembled to the system.

Contamination

If completely pure refrigerant and oil could be sealed within a refrigeration system perfectly clean and free of all traces of other liquids and gases, a very high degree of stability would be the result. An approach to this ideal is made at Frigidaire where the materials of construction are daily measured by the tons, but the contaminants rigidly controlled and counted by the milligrams. Just as with drinking water—dangerous bacteria never amount to much in terms of weight per cent but the water is nonetheless contaminated.

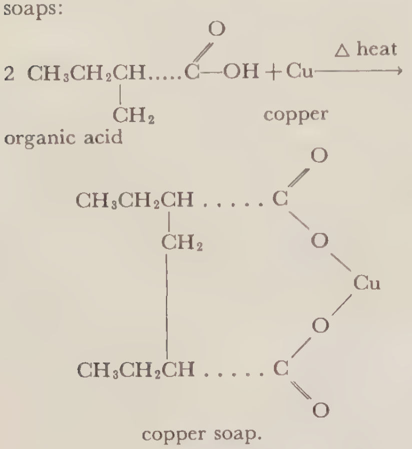
An ever-present but always unwanted contaminant is air. It is, of course, present on the interior of the system until evacuated. Substantial quantities could enter as dissolved gas in the oil and the refrigerant itself. Air can be responsible for many troubles. If enough is present it can make itself immediately obnoxious as an efficiency-reducing non-condensible gas on which the compressor does work but produces no refrigeration. Lesser quantities proceed to oxidize the lubricant or the motor insulation, generally resulting in acidic products and, finally, copper plating or even corrosion of the metals:



$$\underset{\text{lubricant}}{CH_3CH_2\underset{\underset{CH_3}{|}}{CH}\ldots\ldots CH_3} + \underset{\text{oxygen}}{2\,O_2} \xrightarrow[\text{catalyst}]{\triangle\ \text{heat}}$$

$$\underset{\text{organic acid}}{CH_3CH_2CH_2\ldots\ldots\overset{\overset{O}{/\!/}}{C}{-}OH} + \underset{\text{water.}}{H_2O}$$

Oxygen can be responsible for gumming, even tarring of lubricants. Corrosive water is a by-product of the oxidation reaction. The organic acids further react with the metals of the system, particularly copper, to form, most probably, copper soaps:



This reaction is reversible and copper is redeposited at hotter points, in part due to thermal decomposition and because of other effects. This phenomenon is called *copper plating* and can, under the worst circumstances, lay down a sufficient thickness of copper to interfere with the movement of compressor parts. This redeposition is also the reason why analysis for copper in oils hardly ever shows over ten parts per million in solution. Iron is also attacked and converted to a soluble organic compound. It is apparently not as easily redeposited as concentrations of several hundred parts per million can be found in the oil under some conditions.

To avoid the host of possible troubles due to air, thorough precautions are taken to keep it down to an insignificant level within the system. Refrigerant manufacture is closely controlled to limit dissolved air. Lubricant is vacuum deaerated in special equipment to remove the last traces of dissolved air (Fig. 5). All systems are thoroughly evacuated before final charging with refrigerant and oil.

Fig. 6 shows a small portion of the huge multistage steam jet system which is used to create high vacuum, measured in microns of absolute pressure, in sufficient capacity for mass production operations. Constant laboratory and production checks insure the proper operation of this equipment.

Water is another ever-present contaminant which must be kept to very low levels if high chemical stability is to be attained. Small quantities can enter dissolved in the refrigerant; therefore, special drying procedures limit this to ten parts per million. Oil, likewise, could bring in dissolved water and is carefully dried by blotter pressing and vacuum operations until it is at no more than ten parts per million water content. The motor insulation could retain substantial quantities of water and even internal metal surfaces could sorb measureable quantities. Removal of this water is accomplished by high vacuum-heat dehydration (Figs. 7 and 8).

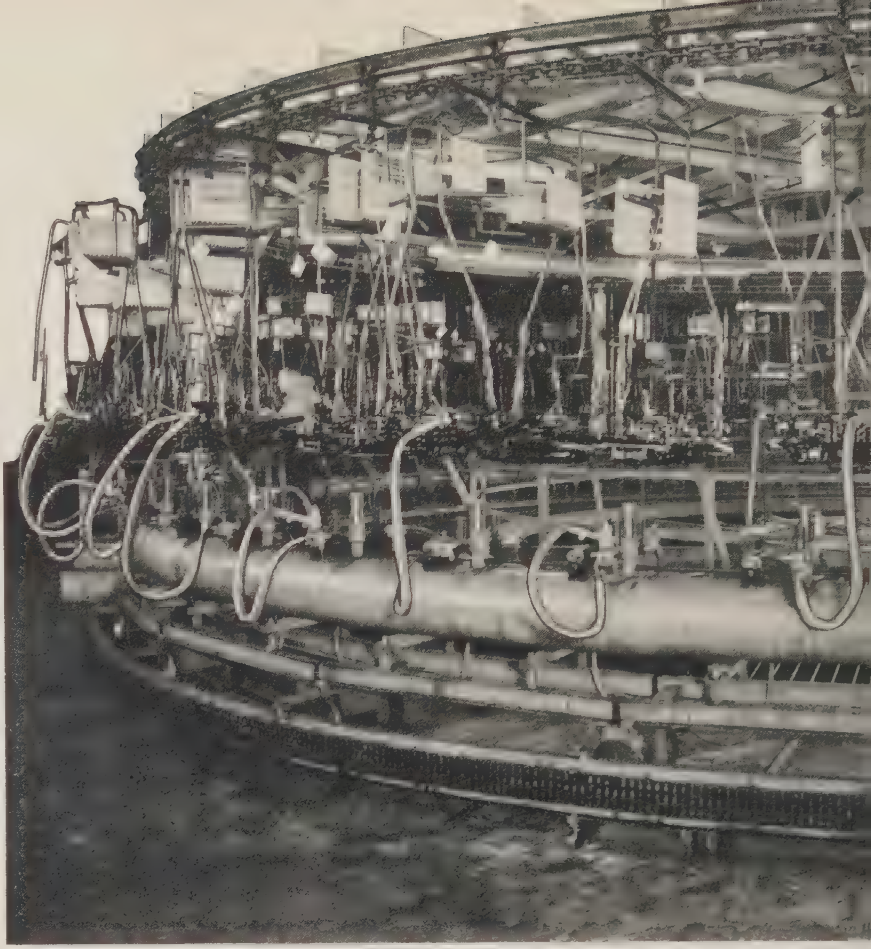


Fig. 8—Completely assembled household refrigerator systems are further vacuum dehydrated on hu slow-turning, wheel-shaped fixtures. The required vacuum exposure is normally imposed in one rev tion of the wheel.

Within the system, water can react in its own right or it can catalytically cause reactions which would ordinarily not occur. Staining and metal corrosion can occur directly. Hydrolysis reactions proceed on the motor insulation and even on the refrigerant.

$$\underset{\text{Freon 12}}{CCl_2F_2} + \underset{\text{water}}{2\ H_2O} \xrightarrow[\text{catalyst}]{\triangle\ \text{heat}} \underset{\substack{\text{carbon}\\\text{dioxide}}}{CO_2} + \underset{\substack{\text{hydrochloric}\\\text{acid}}}{2\ HCl} + \underset{\substack{\text{hydrofluoric}\\\text{acid.}}}{2\ HF}$$

The listed equation is, no doubt, a simplification of the true mechanism but the fact that hydrolysis occurs even w the most stable Freons has been esta lished (Fig. 9). True, the reactions very slow and with minimum wa quantities they can be ignored with most stable Freons. At 122° F, in presence of steel as a catalyst, some co parisons can be listed as follows[1]:

Degree of Hydrolysis	*Gram per li per ye*
Methyl chloride	110
Methylene chloride	55
Trifluorotrichloroethane (Freon 113)	40
Monofluorotrichloromethane	28
Difluorodichloromethane (Freon 12)	10
Monofluorodichloromethane (Freon 21)	9.

In general, Freon 22 is as good somewhat better than Freon 12 in comparison of this nature. All th rates are almost negligible when co pared to other types of organic compoun

Also, water can cause a *freeze-block* the refrigerant expansion points in ca lary tubes or expansion valves. Th although factory heat-vacuum dehyd on procedures limit the moisture in ompressors and systems to 0.10 g or ss (in the smaller models) antifreezes or riers must still be included to neutralize ven this quantity. This is necessary as, nder certain conditions, with the smaller iameter capillary even 0.01 g of water an cause a freeze-block which effectively revents refrigerant circulation and, hus, stops all refrigeration.

In the smaller, self-contained package ystems, driers are included to take up the ast remaining traces of water. Commonly used desiccants are calcium sulphate, silica gel, or alumina. Driers must e designed to resist powdering which ventually plugs capillaries or expansion alves and to offer little or no resistance o refrigerant flow.

In the larger systems, driers can be sed but antifreezes are more common. Minimum quantities of methanol are dded to prevent the freezing of water at he capillary discharge or expansion alve. This is effective in preventing reezing of water but it is not quite as deal as a drier since the small quantities f water and alcohol remain to cause hemical reactions.

Other contaminants to the system ould be introduced with the various omponent parts during the manufacturing operations. Residues from cleaners, cids, plating solutions, cutting compounds, cooling and drawing solutions, older and brazing fluxes, solvents, heat-treat salts, and even perspiration residues ould all cause trouble in their own right r else accelerate or catalyze the general eat reactions between oil, refrigerant, nd metal if carelessly left on internal urfaces. In consequence, thorough cleaning operations are applied before final ssembly and residue checks are run aily by the laboratories on incoming naterials and on all phases of production rocessing of components. An ideal which s constantly kept in mind is that all nternal surfaces should have no more han 0.002 g per sq ft of any type of esidue on them when assembled into the ystem. Besides their chemical reactions hese contaminants could plug screens nd capillary lines or expansion valves.

Of course, all of the deteriorating orces and materials mentioned affect ractically all mechanisms, but only a ew other mechanisms are required to unction with all their deterioration roducts for long life—without any assisting maintenance. Also, few other machines have the critical clearances, tolerances, and flow control which must be maintained in the refrigeration system. For instance, all of the household rotary compressor pump parts are controlled to clearances of 0.0001 in. to 0.0003 in. and all angularity, line-up, or eccentricity clearances are held to the same magnitude. Consequently, a piece of dirt, a tiny chip, a spot of copper plating, an area of corrosion, or a little oil varnish as small in amount as 1 mg could wedge a vane or impair the performance of a check valve. This does not mean that every single milligram does do this, but rather that a certain proportion of failure can be due to minute effects.

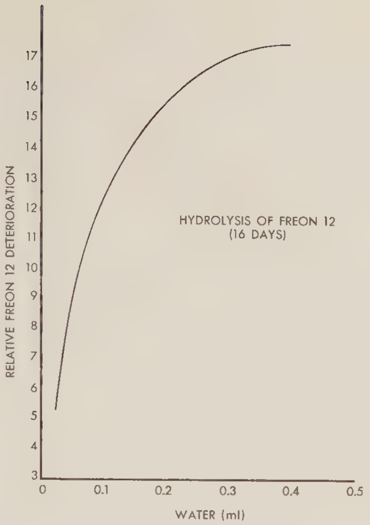


Fig. 9—Results of tube tests confirm the effects of water on Freon 12 decomposition. The tests utilized steel and copper strips as the catalysts—just as in an actual refrigeration system.

Summary

Within the past generation, Frigidaire refrigeration equipment has been developed to high reliability and long life through experience gained during the course of manufacturing nearly 16,000,000 household units. This was possible, in great part, to research which has lead to the improvement of chemical stability within the system. Major deteriorating factors are heat and catalysts and these have been minimized by the development of highly stable refrigerants, lubricants, and motor insulation. Another deteriorating factor is contamination which is constantly battled by intensive drying and evacuating procedures and rigid control of all processing. Intensive research on both materials and processing continues in an effort to meet still higher requirements in temperatures and smaller power packages.

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Some Personal Lessons from Five Decades in Engineering

In nearly half a century of automotive engineering, many changes are observed—changes in the basic concept of automobiles, in economic conditions, in engineering methods, and in manufacturing procedures. In fact, nearly everything has changed except the people and what makes them click. The personal qualities of engineers that meant success at the turn of the century seem to be the same qualities that are important today. After almost 50 years of dealing with engineers, some personal observations on these qualities may be of interest to younger engineers just embarking on their careers—just as a motorist who begins a trip over a new and unfamiliar route can get information about the road ahead from the approaching driver who has passed over much of the same road.

THE young engineer, leaving college and entering industry, is usually showered with advice from all sides. That is probably because advice is the cheapest commodity there is and, therefore, the least desired. More than advice, the young engineer needs experience—and experience is often very costly. Most technical experience must be gained the hard way—by making mistakes and correcting them. On the other hand, experience in dealing with people can be gleaned from old-timers who have lived through many personal experiences.

The technical complexion of the automobile has changed year by year. The hand-started touring car with the droopy top of the World War I era hardly bears a family resemblance to the sleek, automatically controlled cars of today (Fig. 1). But the same personal qualities that made men successful at the turn of the century are present in the leaders of today. It is those personal qualities that I would like to discuss in the light of nearly fifty years' experience with all kinds of people.

At the turn of the century, when the automobile was the rich sportsman's toy, everybody worked hard and long. Nine or ten hours a day, six days a week was quite normal. A salaried position was something to strive for and to be proud of. Salaried people assumed a lot of responsibility and took pride in doing a little more than they were paid to do. There was no pay for overtime. Things were quite different in those days, but the man who was honest and sincere and had ability and energy generally worked his way up the ladder to success. The same path to success is open to the young engineer of today if he backs up his technical ability with desirable personal qualities and experience.

The Right Attitude

Every young engineer makes a difficult transition when he first enters industry after completing his college education. He is likely to make mistakes, and no one will hold his mistakes against him *if* he makes an honest effort to correct them. Much depends on his attitude if he is to make a successful transition into industry. If the young engineer assumes a superior attitude he can expect little help. If he is humble and admits his lack of experience nearly everyone will extend a helping hand.

The attitude of the young engineer toward his work is of the greatest importance. When he honestly enjoys his work he approaches each new day on the job as a challenge to his ability, ingenuity, and ambition. With this happy mental attitude, he is eager to see what the day will bring and how he can solve its problems and, when each day is done, he can feel as if he has been in a spirited but friendly competitive game and has won.

Every job includes some distasteful duties, so the young engineer should not become discouraged too easily. He must learn to enjoy doing what his engineering job requires him to do if he is to get real enjoyment from his work. If he just cannot enjoy his work, perhaps he is working for the wrong company or in the wrong department. If this is the case, he will do himself and his employer a favor by finding a job where he can be happy.

Building a Reputation

When the young engineer enters in dustry, he begins to establish a reputa tion. The building of that reputatio begins with the first calculation or th first instrument reading he makes, wit the first line he draws, or with the fir letter he dictates and the building proce continues with every personal contact h makes (Fig. 2). Like any structure, reputation is not built completely in day or a week. It rises slowly, stone b stone, upon the footings.

I like to think of education as the foo ings of every man's career. If the footing have not been laid deep and wide an strong they must be strengthened b supplementary college courses at nig or by judicious private study, if t structure of his reputation is to be wel supported.

When the young engineer starts build a reputation, his early mistakes c be corrected quite easily. The trick is t find the mistakes early enough so tha an effective correction can be mad When a mistake recurs too often it ma become a habit which can seriousl damage a promising reputation. Then, i is usually necessary to over-correct. As a example, if a young engineer starts ou with utter disregard for accuracy, a early correction can be made withou hurting his reputation too much. But, i the correction is postponed too long he has established a reputation for being inaccurate. Then, the correction must be overdone. Instead of the usual one pe cent leeway, accuracy must be held within one tenth of one per cent—just to prove that the reputed failing has been overcome.

There are many things which will help to establish a good reputation for the young engineer. These include always doing his best on the job, looking beyond his exact assignment, never giving a sna answer unless he is reasonably sure tha it is the right answer, backing up hi

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When stepping into larger shoes the size of the hat should remain the same

riticisms with specific remedies, being eliable, and being decisive.

A good reputation can often be eriously damaged by tardiness. It goes uch deeper than the hours and minutes ecorded by the time clock. The man ho is habitually late for work usually rocrastinates about getting his job asgnments started and finished, and plain ordinary procrastination has wrecked more promising careers than lack of technical ability. Getting to work on time requires a certain amount of organization and preparation. How can a man who fails in such a simple organizational task be entrusted with the organization of an engineering project? In my experience, tardiness is just evidence of inaccuracy. I have never known a man who was noted for doing accurate, meticulous work who did not enjoy a reputation for punctuality.

All these qualities, and many more, combine to build the engineer's reputation. He builds it stone by stone on the foundation of his education. He alone determines the nature of his reputation structure. He can make it a glittering skyscraper reaching to the stars or a tumble-down shack.

Ideas

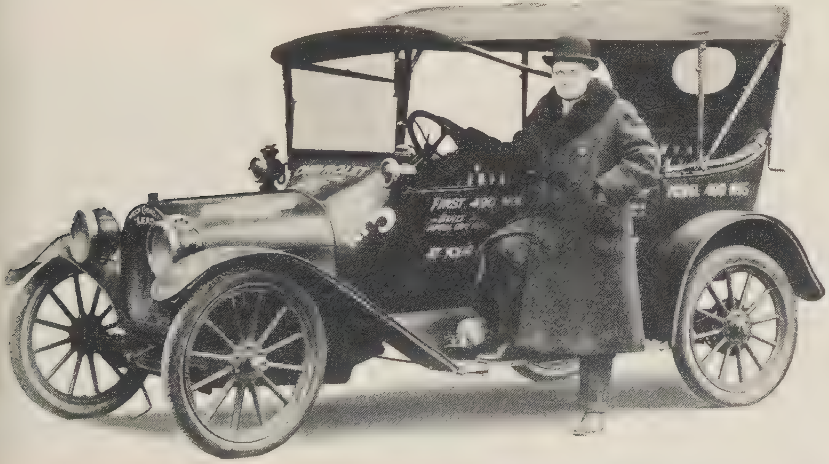
Ideas are of the greatest importance in engineering. They are the very life of our profession. Around the drawing board and in the laboratory, ideas are usually hatched at least one a minute. Some are good but the majority are usually bad. This is the very nature of engineering.

Every young engineer, after he progresses beyond the detail drafting stage, is expected to have ideas. That quality is his stock in trade. Ideas are what he is paid to produce. They are the objective of his education.

Every phase of each engineering project invites new ideas. However, it is well to remember that very few ideas are entirely original. The idea that pops into the young engineer's mind may be new *to him*, but it probably has been thought of by dozens of people before. He is merely applying an old idea to the solution of an immediate problem. In most cases, discussion of the problem only sets the stage for his idea.

Because automotive designing is necessarily a cooperative effort, it is usually difficult to determine who originates any specific idea. One person will contribute an idea and another person may raise an objection. Another person will come up with a modification to overcome the objection. The person who voiced the first suggestion proposes another modification, which again makes the rounds. That is why it is often difficult to determine who really originated a design idea and who should get credit for it.

That question of who shall get credit for an idea is something the young engineer should be careful to keep in mind. When he is engaged in a design or development project, he is expected to contribute ideas along with everyone else. If he hugs his little piece of an idea possessively to his chest and loudly pro-



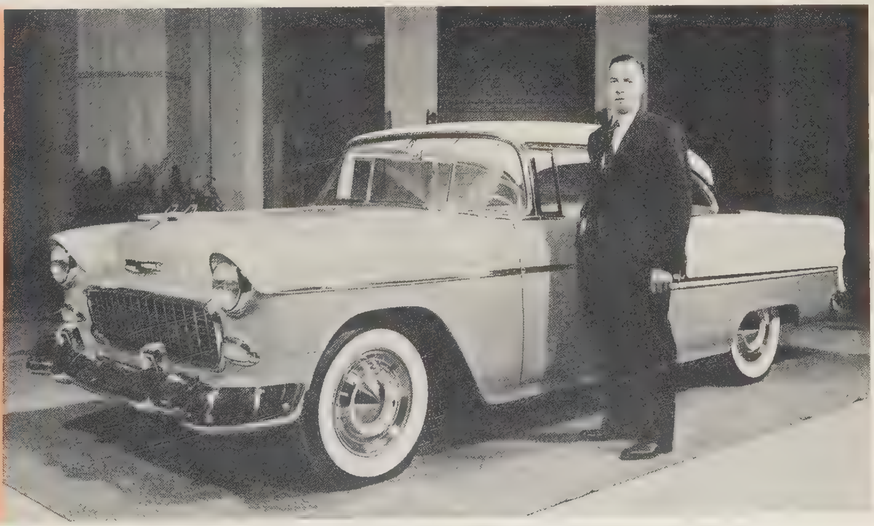


Fig. 1—Many changes have taken place in the basic concept of the automobile since its early stages of development, as evidenced by these illustrations. The striking difference between the 1915 Chevrolet "490" model (above) with R. H. Grant, retired former vice president and director of GM standing beside, and the 1955 Chevrolet Bel Air (right) with E. N. Cole, present chief engineer of Chevrolet Motor Division standing beside, clearly indicates the advancement made in automotive engineering as a result of technical experience gained by engineers in their endeavor to provide the public with the utmost in motoring pleasure, safety, and economy.

Fig. 2—The young engineer's first days in industry serve to establish the foundation for his reputation. The building of his reputation might begin with the first calculation made or the first instrument reading taken. His reputation will continue to grow with his every action and personal contact and will depend on many personal qualities as well as technical ability.

claims, "That's my idea," he brands himself as an "idea hound." Nothing will serve as a more effective repellent to help from his associates, which the young engineer will need so badly. No engineer has a corner on all the good ideas, and the smart engineer does not hold on to every one of his ideas as if it were the last one he ever expects to have.

Cooperation

Engineers must work together to accomplish the desired results. In a well-organized engineering department nothing worth-while is accomplished without cooperation. Engineers working together, with the help of draftsmen, designers, mechanics, and technicians, can accomplish wonders in carrying out their specific assignments (Fig. 3).

Every young engineer must decide for himself whether or not he is going to be cooperative. He must decide whether he will carry his share of the work load willingly, help his fellow workers, accept assignments beyond his regular duties, and operate in line with the spirit of departmental regulations. That decision may well have an important bearing on his future success.

As he gains experience, the young engineer will find out that in a well-integrated engineering organization en neers can accomplish little as individua Cooperative effort is what counts m and the young engineer who learns ea to cooperate will profit the most in long run.

Promotions

The man who does exactly what job requires and nothing more will pro ably hold his job if he does it well. T chances for his promotion to a bigger j are pretty slim, however, because no o knows that he might be capable of doi something more.

The man who takes on assignmen that are not part of his regular duti unless they are outright impositions, w soon outgrow his job and force his bo to recognize his ability to handle a bigg job. If it seems that recognition is laggin the young engineer should look for wa to do more work or better work. T extra effort will never fail to pay o

A promotion has different effects different people. Some men who are pr moted get the idea that they have arrive

Fig. 3—Whether he is conducting a laboratory test or seeking answers to a design problem, the your engineer must recognize the value of cooperation. In the well-integrated engineering organization, fe projects are completed by an engineer as an individual. The engineer must be able to supply his own idea but he must cooperate with other engineers, technicians, or mechanics in order to carry out his assig ments successfully.

d that there is no further reason to put rth effort. The wiser promotees conler their promotion as an opportunity put forth even greater effort, not only justify their selection, but to qualify : the next step up.

Obviously, the man who is just a little prehensive about his ability to handle s new and bigger job is likely to do a od job. Therefore, he is likely to be a od prospect for the next step up the dder of success. Many men have failed cause of a "swelled head." Relatively v failures have been due solely to lack technical ability. As long as a man mains humble, there is little danger of ilure. It is when the young engineer tgrows his hat that he has cause to orry. Strangely, when *he* begins to think at he is pretty good, other people gin to think otherwise.

When the young engineer is promoted, is wise for him to take an honest invenry of himself (Fig. 4). He should ask mself, in complete honesty and humil, "Why was *I* selected for the new b, and what do I have to contribute to e job?" Without egotism, he should so answer the question, "Where can I from here?" His answer to these quesons, and the action which his answers ay stimulate, will prove conclusively hether he really has what it takes to get ead or whether his superiors have erated him.

The young engineer's first promotion probably the greatest challenge he will er face. It can swell his head or shrivel s soul. If it does either of these he does t deserve the promotion. If he gets a elled head he is convinced that he has rived and he will probably not strive do his best on his new job, much less ll he prepare for the next job ahead. his promotion shrivels the young engier's soul he will find himself in trouble. ne new job should not frighten him to e point where it becomes his master. nless he can feel that he is on top of e job, or in position to get on top of then the job to which he was promoted not the right one for him.

Decisions

An insidious foe of personal progress is decision. Many engineers who do outanding work on the technical side of eir jobs fail miserably when it comes to aking decisions. To them, making a cision is really a difficult task. They ould rather propose several alternate designs than to be decisive in selecting the one best design. This habit of proposing alternates rather than making decisions can really retard a man's progress, and engineers who have this bad habit need to discipline themselves to be decisive.

Fig. 4—The young engineer's first promotion is probably the greatest challenge he will ever face. It is at this time that he should make an appraisal of his personal and technical qualities in an effort to see whether he really has what it takes to get ahead or whether his superiors have overrated him.

The man who would influence the opinions of others must learn to make up his own mind. Making decisions is not a hard job. It requires only that all of the pertinent facts be weighed in the light of one's best judgment—based on his own knowledge and experience—and then to decide on the best course as he sees it.

The young engineer should not be unduly concerned about having his decisions reversed—everyone does. In my experience, his boss will have a higher opinion of him if the engineer makes a decision that he can reverse rather than making no decision at all. The young engineer can learn something from each decision that is reversed. Usually, the reversal is made by someone in higher authority who has had more experience. The wise engineer takes advantage of that experience to help him make better decisions in the future. Above all, he should not pout and brood over every reversed decision. On the contrary, he should present his rebuttal calmly, listen to the explanation of why the decision was reversed, and then remember that explanation for his own future benefit.

Summary

Five decades in automotive engineering have provided a few guides to be helpful to the young engineer on his way up the ladder of success:

- *Treat them nicely on your way up—you may meet them on your way down.* The young engineer whose drafting technique and lettering I criticized unmercifully became my chief engineer. He had more on the ball so he passed me on his way to the top. Fortunately for me, he realized that my criticism was in the best interest of the operation. Had my criticism been out-of-line, and had the chief engineer been a less understanding individual, the results might have been quite different for me.
- *Be true to your profession.* Because of his education, and by his own choice, a young man finds himself in the engineering field. It is a profession to be proud of. It requires certain standards of living and action. By conforming to those standards the young man entering industry proves himself to be worthy of his chosen profession.
- *Above all, be a man.* The young engineer starting out in industry may never attain the top position in his field, but he can always live up to the code of manhood. When he comes to the end of his career, all he will have left are his conscience, his material possessions, and the regard of his colleagues. The importance of material things will lessen with the passing of the years, but the voice of conscience will become louder and the regard of his colleagues will become more important.

The young engineer entering industry is on the threshold of a useful and interesting career. How he ends that career is of his own choosing. He, and he alone, will decide whether or not he will be rated as a man by his colleagues on that far-distant day when he comes to the end of his engineering career.

A Discussion of Design Principles and Their Effect on Economical Processing of Molded Plastic Products

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Inland
Manufacturing
Division

Sound plastic product design essential to low-cost processing

The objective in planning the design of a molded plastic product is to incorporate into the design those features which add the most to product usefulness and appearance. Of prime importance, also, is to design the product so that it may be processed using the most economical methods. In order to do this, consideration must be given to the design features which eliminate excessive production scrap, expensive direct labor operations, high tool cost, and needless accuracy. It is necessary for the designer to have a versatile knowledge of the problems involved in the molding and finishing of plastic products in order to properly select the material, to specify tolerances, and to plan the detail product design features. Low-cost processing can only be realized when the designer considers the effect of each design feature on efficient processing and the cost of the finished product.

WHEN undertaking the design of plastic products, many factors must be considered in order to plan a design which will be economical to process. The designer should have a knowledge of the effect of such design features as material selection, tolerances, and technical details of the molding and finishing phases of processing plastic products.

The majority of plastic products produced at Inland Manufacturing Division are made of thermoplastic compounds and are molded by the *injection method*, wherein a thermoplastic compound is plasticized in a heating cylinder and then forced under pressure through one or more orifices into a relatively cool mold where the material solidifies.

At Inland Manufacturing the design of injection molded plastic products is classified as either *decorative* or *non-decorative*. A *decorative product* is one which is molded of a transparent plastic resin and painted or metal-vapor coated on the back or the side not visible in its final assembly position. The front side of the product design is of smooth and uniform construction, while the back side is quite complex in design and may include design patterns such as scrollwork, names, or trademarks of the product to which it will later be assembled, or functional numbers and letters. Examples of decorative products include steering-wheel horn button caps, automotive hood and deck emblems, and miscellaneous dials, indicators, and name plates for the refrigeration and automotive industries.

Non-decorative products are those molded of either translucent or opaque plastic resins which contain the color requirements of the finished product as molded and, therefore, do not require such subsequent operations as painting and metal-vapor coating. Steering wheels, instrument knobs, refrigerator hydrator box covers, door locking knobs, and ice tray grid assemblies are examples of injection molded plastic products that fall into the class of non-decorative designs.

The general procedure followed in processing both decorative and non-decorative products is the same with the exception that, by definition, non-decorative designs are not painted or metal-vapor coated. The general sequence of manufacturing operations followed in processing injection molded plastic products is as follows:

(a) Thoroughly dry plastic resin before molding
(b) Load resin into hopper of injection molding machine
(c) Mold. Remove pieces from mold
(d) Remove solidified gate from piece by one of the following methods:
  hand clipping
  sawing
  milling
  sanding
(e) Machine all cored sections, undercuts, and other requirements which are not practical to mold
(f) Remove flash line formed at mold parting line by scraping and sanding
(g) Anneal*
(h) Mask piece and paint or me vapor coat on one side*
(i) Buff piece with special abras compound and soft cloth
(j) Clean piece of all buffing co pound and finger marks.

*Decorative designs only

From the manufacturing standpoi the factory cost of any plastic prod may be measured in terms of four facto material, direct labor, burden, a tooling.

The material cost of most plastic pr ucts may be considered a constant. determined by the overall size of design. Intricately designed plastic pr ucts containing design features that h been determined difficult to mold m bring about an increase in material due to a percentage increase in mo ing scrap.

The direct labor cost of plastic pro ucts is governed directly by the numb and complexity of processing operatio required to produce the design.

With respect to the tooling cost plastic products, as the detail features the design become more complex, cost of mold construction and finishi tools increases proportionally.

The approach to designing an inj tion molded plastic product which be economically processed may be brok down into four areas of planning as lows, with each area having a spec effect on low-cost processing:

- Detail design features
- Material selection
- Tolerance specifications
- Finishing requirements.

Detail Design Features

Various design features such as m tolerances, fillets and radii, draft allo ce, taper, undercuts, inserts, and color quirements have a decided effect on e molding phase of processing. Im- oper design features result in high mold nstruction costs or poor quality mold- gs, or both.

old Tolerances

The finished tolerances which can be ld on any plastic product are con- olled by the accuracy which can be ld in building the mold cavity and on e shrinkage rate of the material being olded. In the construction of a mold r plastic-product production, a work- g tolerance of ±0.005 in. on any itical dimension is considered to be actical. If dimensioning requires greater curacy, a tolerance of ±0.002 in. on itical dimensions can be held. This will sult, however, in a 15 per cent to 20 r cent increase in the cost of mold nstruction.

llets and Radii

As a general rule, the use of fillets and dii in the design of plastic products sults in a lower cost of mold construc- on. This is because of the fact that, in ost cases, standard radius cutting tools n be used. From the design standpoint, wever, more importance is given to e improved quality of molding brought out by the use of fillets and radii than the cost of mold construction.

There are numerous reasons why fillets d radii are desirable in the design of a astic product. The use of fillets and dii permits easy flow of plastic into the vity, allows less chance of trapping air ithin the cavity as it is filled with astic, lessens stress concentrations which mmonly develop where sharp corners ist, adds strength to both cavity con- ruction and the molded piece, lessens e noticeability of material warpage fol- wing molding, and does not reflect emishes as much as sharp angles.

raft Allowance and Taper

In molded plastic parts, draft should specified wherever possible. If draft es not interfere with the functional or corative aspects of the design, two grees is recommended for all sections rpendicular to the mold parting line. is sometimes possible to use less than o degrees, depending on the depth of e section, but such practice usually cessitates the use of a more substantial ockout mechanism.

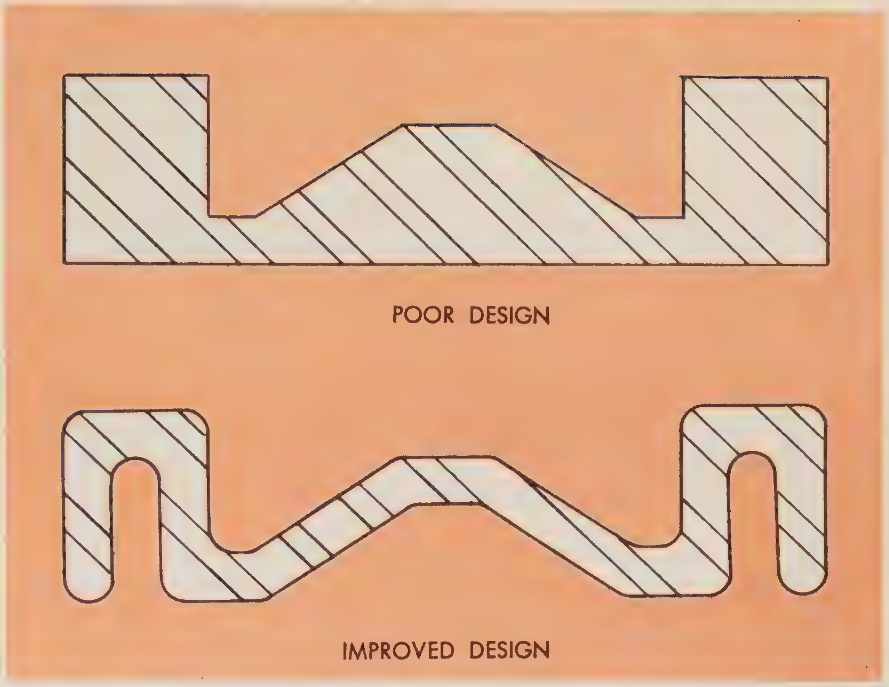


Fig. 1—The cross-sectional design of a plastic product should be as uniform as possible. This figure illustrates an improved product design which results in lower material usage and reduced molding time. A higher quality molding also results, due to less internal stress concentration, less distortion following molding, and added strength.

Undercuts

Undercuts in plastic work should be avoided if at all possible as they serve to increase the cost of the finished product. The cost of an undercut design feature may be measured in terms of added mold construction cost or additional direct labor expense. The cost of mold construction is increased by the necessity of removal pins, cores, sliding sections, and other parts, in order to mold the undercut feature. The molding time itself is usually increased to allow the molding to normalize properly so as to minimize distortion and to permit unobstructed removal of the piece from the mold. This additional molding time required for normalization adds to the direct labor cost of the molding operation. The operation or handling of loose or sliding mold sections required to mold undercuts may also require additional direct labor. In some cases, it is more economical to machine undercuts rather than to mold them. An example of this might be a design containing a threaded hole which could be drilled and tapped by the press operator during the closed mold part of the press cycle time. This method of processing an undercut is determined by such factors as the machineability of the plastic resin being molded, the closed mold time, the volume of the job, the number of cavities in the mold, and the effect of molding the undercut on scrap.

Irregular Cross Sections

The cross-sectional design of a molded plastic product should be uniform and as thin as strength requirements will allow. Some of the disadvantages of irregular cross sections are: (a) tolerances are harder to hold because of uneven shrinkage rates set up within the cross section, (b) an overall weakening effect on the piece due to the presence of internal stress concentrations, (c) undesirable material flow characteristics in the mold cavity, and (d) an increase in the closed mold time due to the longer normalization period required in order to prevent severe distortion. Fig. 1 illustrates how an improvement can be made in the design of a plastic product so as to keep the cross section as uniform as possible.

Inserts

When it is necessary to use inserts in the design of a plastic product it is important to surround the insert with enough plastic to absorb shock and to prevent fracture. It is wise to use inserts that have no sharp angles or corners which would be likely to set up stress concentrations during molding. Inserts should be designed with chamfered edges

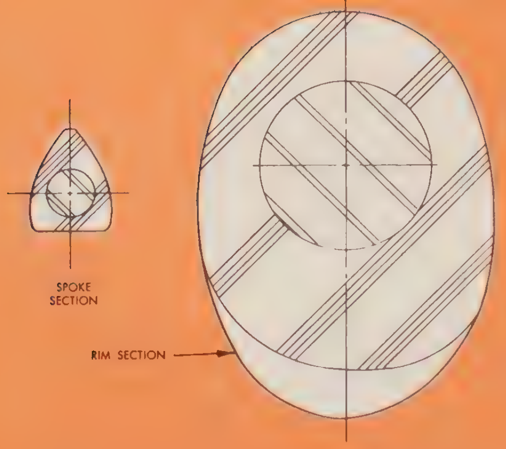
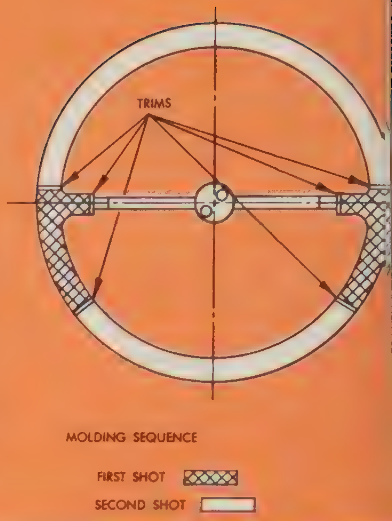


Fig. 2—Inserts should be centrally located within a plastic product and surrounded with enough plastic to absorb shock and to prevent fracture. This figure shows well-designed inserts used in a steering wheel spoke and rim.

Fig. 3—When a multi-colored plastic product is desired it is necessary to use separate molding operations and cavities for each color. This figure illustrates a two-color plastic steering wheel which required the use of two separate molds. One color of plastic was shot into the first mold in such a way that only a definite section of the mold was filled. The wheel was then flashed and transferred to a second mold where the second color of plastic was injected and the mold completely filled. Chromium trims were necessary wherever a color line existed.



and radii at all corners. Fig. 2 illustrates an insert placement in a steering wheel rim and spoke.

Color Requirements

The color possibilities of plastic molding resins are practically unlimited. The important design feature to remember, however, is that only one color can be molded at a time. If a multi-colored product is desired, separate molding operations and mold cavities are necessary for each color. The two-color plastic steering wheel is an example of this application (Fig. 3). A *marble-type* pattern may be obtained by molding a mixture of several different colored plastic resins.

Material Selection

Among the initial design considerations which must be made by the designer of a plastic product is that of material selection. The selection of the material of which the product will be molded depends on the physical properties required in the finished product and on the effect the material will have on economical processing methods.

The selection of a material that will meet the physical property requirements of the finished product depends on the strength required, the color effect, and the surroundings to which the finished product will be exposed. The selection of a material which will be economical to process depends on the material's flow characteristics, thermal conductivity, uniformity of granular structure, plasticizing rate, purity, machining qualities, effect of metal inserts, and shrinkage rate.

Table I lists various properties and characteristics of five thermoplastic compounds widely used at Inland Manufacturing in the injection molding of steering wheels, horn button caps, name plates, and numerous other decorative and non-decorative products.

Tolerance Specifications

The tolerance which may be assigned to the dimensions of a molded plastic product should be determined from the material shrinkage rates given in Table I and from the location of the *cavity gate*—the point through which molten plastic is injected into the mold cavity. The final location of the gate is generally determined by the molder. The designer, however, should be familiar with the processing considerations involved in the location of the gate so that proper design allowances can be planned.

In the injection molding process, high internal stress concentrations are built up within the mold cavity after the injection ram has reached its full forward position. Preliminary material solidification begins as soon as the cavity has been completely filled with plastic. The point of initial material solidification is usually the point in the design at the opposite end from the gate location, since the molten resin is cooled as it flows away from the gate. The injection ram cannot be withdrawn from its forward position until either the entire piece has solidified or the injection gate itself has frozen. It is during this time in the molding cycle, when the injection ram is still exerting a pressure trying to pack more material into the remaining unfrozen portion of the cavity, that high internal stresses are set up. This stress condition tends to distort the piece following its removal from the mold and also results in a material contraction about the gate which may vary from 0.001 in. to 0.005 in.

The contraction and resulting hig
stress concentration are factors which t
designer of a plastic product must kee
in mind in order to plan allowances f
gate positioning. In a design in whi
the physical tolerances are critical, allo
ance should be made to gate the pie
in a location which would permit a u
form and balanced flow of material as
fills out the cavity. This procedure mi
mizes the distortion which would oth
wise exist. The injection gate, when
positioned, can then be removed a
molding by various milling, sanding,
buffing operations if the gate is obj
tionable to the appearance of the finish
product. The main advantage of gating
part on the side, or in a non-central loc
tion, is that costly finishing operatio
required to remove the gate are som
times avoided. The designer should kee
in mind that, when possible, many pro
ucts can be designed so that the gate m
be located in a position that will n
detract from the appearance of t
finished product and, thus, gate remov
does not become a critical finishing ope
ation. This is particularly true of deco
ative designs in which the product m
be used only as an insert which is,
turn, assembled to a larger product. T
amount of overall distortion which w
result from a side gate location cannot
accurately predicted, as it varies relati
to the gate location and design chara
teristics.

Table II shows a list of practical wor
ing tolerances as applied to five plast
compounds used at Inland Manufactu
ing. It should be remembered that the
tolerances should be assigned in co
junction with the previously discuss

lerance effects of gating and mold con- uction on the overall design.

Finishing Requirements

Both decorative and non-decorative signs usually require common finishing erations such as removing the gate, nding of flash lines, buffing, and final eaning. Decorative designs, however, quire the additional operations of ainting and metal-vapor coating. The ocessing operations required in finish- g plastic products that should be given nsideration in design work are: gate sitioning, painting and metal-vapor ating, and final buffing and cleaning.

ate Location

Location of the cavity gate is again an nportant factor in the appearance of ecorative designs as well as the cost. he flow characteristics of acrylic resins, sed in molding decorative plastic prod- cts, are such that *weld lines* and *flow lines* re unavoidable. The intensity of notice- bility of these lines, however, can be educed if the designer is familiar with e various causes of these conditions.

Weld lines and flow lines are caused by esign features which restrict or divide e flow of plastic as it fills the cavity. A olded hole is an example of a design ature which causes the plastic to divide nd flow around the core pin in order fill out the cavity. A weld line is rmed where the divided flow, caused y a restriction, knits together. This knit- ng action leaves a weld line because e plastic cools down as it fills the cavity nd falls below the temperature at which niform joining occurs.

Decorative products should be designed permit the use of a large gate so that e plastic can be injected into the cavity s quickly as possible. The use of a large ate lends itself to better control over the olding operation and, thus, lessens the oticeability of flow lines and weld lines. some cases, more than one gate is equired to inject plastic into the cavity. his design condition always results in eld lines forming where the resin from ach gate knits together. A point to emember when planning the location the injection gate is that weld lines ways form along a line extending dially from the gate to the cause of the ow restriction.

Fig. 4 shows an example of a decorative esign which resulted in an objectionable eld line caused by a flow restriction as

PLASTIC COMPOUND PROPERTIES AND CHARACTERISTICS CHART

PROPERTIES AND CHARACTERISTICS	POLYVINYL CHLORIDE	CELLULOSE ACETATE BUTYRATE	POLY-STYRENE	POLY-ETHYLENE	METHYL METHACRYLATE
Molding Qualities	Good	Excellent	Excellent	Excellent	Excellent
Injection Molding Temperature (°F)	320-385	335-480	325-600	300-500	350-475
Injection Molding Pressure (psi)	10,000 to 25,000	8,000 to 30,000	10,000 to 30,000	10,000 to 15,000	15,000 to 30,000
Mold Shrinkage (in. per in.)	0.010-0.040	0.002-0.007	0.002-0.006	0.020-0.050	0.002-0.005
Specific Gravity	1.2-1.5	1.15-1.25	1.05-1.065	0.092	1.18-1.19
Specific Volume (cu in. per lb)	21.3-17.3	24.0-22.2	26.3-26.0	30.1	23.4-23.2
Tensile Strength (psi)	1,500 to 3,000	2,600 to 6,900	5,000 to 9,000	1,300	7,500 to 10,000
Compressive Strength (psi)	900 to 1,700	7,500 to 22,000	11,500 to 16,000	----	12,000 to 18,000
Rockwell Hardness	Varies with plasticizer	R-60 to R-115	M-65 to M-90	R-11	M-85 to M-105
Effect of Sunlight	Varies with formulation	Varies with formulation	Turns yellow, dulls surface	Varies	Excellent
Effect of Metal Inserts	Inert	Inert	Inert	Inert	Inert
Machining Qualities	Very poor	Good	Fair to Good	Fair	Excellent
Clarity	Transparent to Opaque	Transparent to Opaque	Transparent 88%-92%	Translucent	Transparent 90%-92%
Color Possibilities	Very Wide	Very Wide	Unlimited	Limited to Opaque	Unlimited

Table I—Design of a plastic product for economical processing necessitates a knowledge by the designer of the physical properties and characteristics of plastic compounds. Particular significance is attached to the shrinkage rate characteristic of a plastic compound as this characteristic, along with the general design of the product, dictates the tolerances which can be assigned to the design and aids in determining the machining dimensions of the mold cavity.

PRACTICAL WORKING TOLERANCES FOR FIVE PLASTIC COMPOUNDS

COMPOUND	TOLERANCE
Methyl methacrylate	0.0015 in. per in.
Polystyrene	0.0020 in. per in.
Cellulose acetate butyrate	0.0025 in. per in.
Vinyl	0.0100 in. per in.
Polyethylene	0.0150 in. per in.

Notes:
- Additional allowances must be made for critical dimensions from gated areas.
- Listed tolerances must be assigned in combination with standard tolerances governing the machining or casting of mold cavities.

Table II—This list of practical working tolerances must be used in conjunction with the tolerance allowed for material contraction around a gated area, from 0.001 in. to 0.005 in., and the tolerance governing the machining or casting of mold cavities.

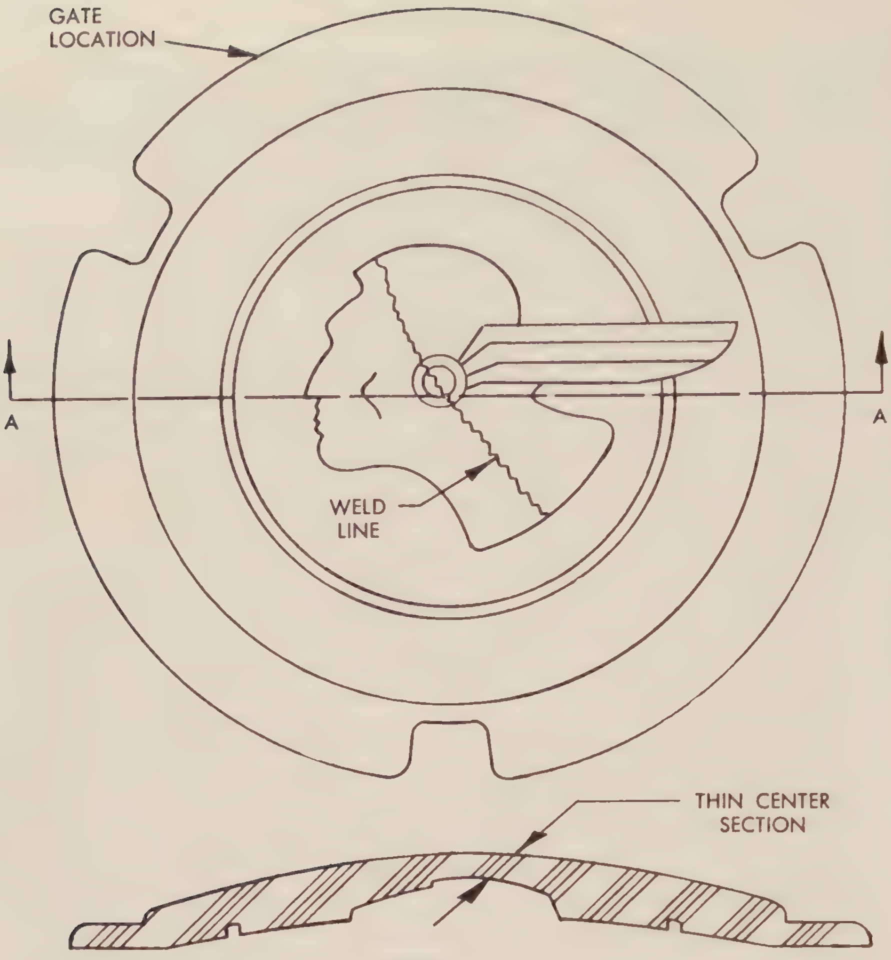


Fig. 4—This illustration shows how a weld line forms over the Indian head because of the restricting nature of the cross-sectional design. The thicker outside edges of this design completely fill with plastic before any material is forced over the Indian head. This condition results in the formation of a weld line as shown because the flow of plastic has been divided and hence cooled by the restricting center section.

originally designed. It should be noted that this particular design was gated on an edge because the tolerance requirements on the flange were not critical and also the cost of mold construction and gate removal was less for this position.

Painting and Metal-Vapor Coating

In decorative designs it is often required that such design features as letters, trade-marks, and numbers be highlighted or made to stand out from the rest of the design. This is commonly accomplished by painting and metal-vapor coating.

Paint is applied to plastic moldings by hand or by the use of automatic spray equipment. Painting by hand is done only when the design is such that masking and spraying are impractical. When automatic spray equipment is used, a painting mask, which shields the area of the product not being painted, is usually used in conjunction with the spraying equipment.

Production metal-vapor coating at Inland Manufacturing consists of depositing aluminum in the form of a thin vapor coating on the surface to be coated. This process must take place within the confines of a near perfect vacuum and may or may not be accomplished with the use of shielding masks. Since the average thickness of a metal-vapor coating is only two or three millionths of an inch, the coating must be backed up or protected by a cover coating of paint. Metal vaporizing is used when the design calls for a genuine metallic appearance. In some cases, lower cost metal-base paints can be substituted for metal-vapor coating when the finishing requirements do not dictate a brilliant metallic appearance. Metal-vapor coating is usually done after painting so that only the remaining unpainted areas are visible from the front
surface of the design. This meth
eliminates the need of separate maski
during both the vaporizing operation a
the spraying of the back-up coat ar
thus, reduces the cost of finishing.

In planning the design of a decorati
product it should be realized that a co
siderable portion of the total cost of t
product is sometimes a function of t
painting and metal-vapor coating oper
tions. These operations are costly becau
of the accuracy required to proper
mask and paint or metal vaporize. It
important, therefore, to plan these desig
features so that painting and vaporizi
masks may be effectively position
during these operations. Fig. 5 illustrat
a typical decorative plastic product. T
design features which have been foun
to make this product more practic
and economical to process at Inlan
Manufacturing are numbered in th
figure and are explained as follows:

1. The width of all recessed design fe
tures such as letters and scrollwo
should be equal to or greater tha
the depth. This permits a unifor
coverage of paint and vapor on the
features.
2. The minimum practical recesse
depth of letters and scrollwork
0.030 in. This is the minimum pra
tical thickness to which paintin
masks are built.
3. The depth of lettering and scrollwor
should be no deeper than one-thir
the thickness of the overall cross se
tion. This insures against a weaken
ing effect on the design due to i
ternal stresses, and also lessens th
possibility of flow lines which woul
detract from the appearance of th
finished product.
4. Recessed letters and scrollwork shoul
have sharp edges on the top surfac
This feature permits more accura
masking than would be possible wit
chamfered edges of a radius.
5. The height of letters and scrollwor
should be limited to $\frac{1}{8}$ in. This is th
minimum practical dimension
which production masking equipme
can be built.
6. Every change in color should occ
at a sharp vertical change in elev
tion, and this change should be
the form of a vertical flat of 0.030 i
minimum height. This is necessa
for proper masking.
7. If painting or vapor coverage of

surface includes a change in elevation, this change should be generously filleted. This recommendation also applies to design features such as grooved or corrugated surfaces. This insures a uniform coverage of paint or metal-vapor coating on these surfaces.

8. If a cup-shaped surface is to be painted or vaporized, the depth of the cup should be held to a minimum. All surfaces to be painted or metal vaporized should be located in a plane parallel to the mold parting line if possible. This insures a uniform coverage of paint or vapor and in some cases will eliminate the need of a second metal-vapor coating operation.

Final Buffing and Cleaning

Cloth buffing and cleaning completes the general finishing operations required for decorative plastic products. The purpose of buffing is to remove any scratches or surface weld lines that would be objectionable to the appearance of the finished product. Buffing is accomplished by the use of special polishing compounds in conjunction with fabricated cloth buffing wheels. Buffing is done on automatic polishing heads with the work being held either by hand or by automatic holding devices.

There are certain design considerations which must be given attention so that the design can be economically buffed. Sharp edges and corners are difficult to buff because they are sometimes hard to get at with production buffing wheels and, also, sharp edges tend to burn easily due to the concentration of buffing friction, which in the case of a corner design feature is pin-pointed on a single edge. Good design practice calls for replacing sharp edges and corners with smooth blending radii. Undercuts or recessed design features on the front side of the product should be avoided whenever possible, as they are physically difficult to buff and are collectors of grit and buffing compound which usually necessitates a subsequent cleaning operation. Square or irregularly shaped designs are costly to buff and clean because they require special handling in order to contact multi-level surfaces and corners.

Circular designs such as horn button caps are ideally suited to buffing because they can be held by automatic chucking devices while being rotated under buffing wheels preset at different angles. With this method, the buffing operator handles the pieces only to the extent of loading and unloading the chucking fixtures.

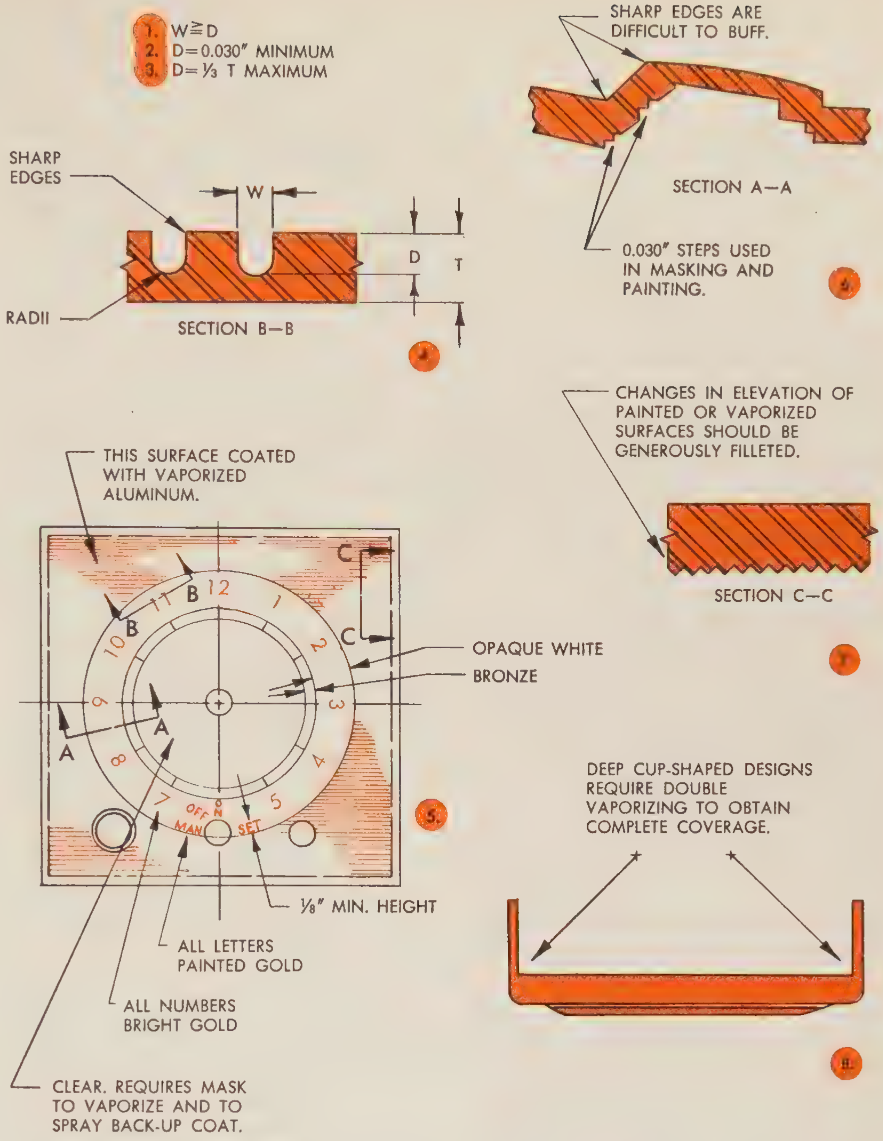

1. W≧D
2. D=0.030" MINIMUM
3. D=⅓ T MAXIMUM
SHARP EDGES
W
D
T
RADII
SECTION B—B
4
SHARP EDGES ARE DIFFICULT TO BUFF.
SECTION A—A
0.030" STEPS USED IN MASKING AND PAINTING.
6
THIS SURFACE COATED WITH VAPORIZED ALUMINUM.
A
B
C
12
1
2
3
4
5
7
8
9
10
11
OFF
ON
MAN
SET
OPAQUE WHITE
BRONZE
1/8" MIN. HEIGHT
ALL LETTERS PAINTED GOLD
ALL NUMBERS BRIGHT GOLD
CLEAR. REQUIRES MASK TO VAPORIZE AND TO SPRAY BACK-UP COAT.
5.
CHANGES IN ELEVATION OF PAINTED OR VAPORIZED SURFACES SHOULD BE GENEROUSLY FILLETED.
SECTION C—C
7
DEEP CUP-SHAPED DESIGNS REQUIRE DOUBLE VAPORIZING TO OBTAIN COMPLETE COVERAGE.
8

Fig. 5—The design features of decorative plastic products that affect the finishing operations are critical from the standpoint of low-cost processing. The design features illustrated in this figure which lend themselves to practical and economical processing are **1** width of all recessed design features should be equal to or greater than the depth to permit uniform coverage of paint and metal vapor, **2** the minimum depth of recessed design features is 0.030 in. to coincide with the minimum thickness of painting masks, **3** the depth of recessed design features should not exceed one-third the thickness of the overall cross section in order to offset the build-up of internal stresses and lessen the possibility of flow lines, **4** recessed design features should have sharp edges on the top surface to permit more accurate masking, **5** the height of letters and scrollwork should be limited to ⅛ in., **6** changes in color should occur at a sharp vertical change in elevation to facilitate proper masking, **7** painted or metal-vapor coated surfaces which have a change in elevation should have this change generously filleted to insure uniform coverage, **8** painted or metal-vapor coated cup-shaped surfaces should have the depth of the cup held to a minimum and all surfaces located in a plane parallel to the mold parting line to permit uniform paint or vapor coverage.

Summary

Economical processing of injection molded plastic products is the result of sound design practice. It is essential that the product design incorporate features which facilitate economical molding and finishing operations. This requires that careful consideration be given to such items as the detail design features, material to be used, tolerance requirements, and the finishing specifications required of the end product.

Judgment, experience, and sometimes compromise are necessary if a sound product design is to be attained. The expenditure of material, labor, tools, and equipment required to manufacture a plastic product will be a reflection of the designer's careful consideration of plastic design principles.

A Survey of the Transistor

During 1954, Delco Radio Division established a semiconductor laboratory and assigned to it physicists, mechanical and electrical engineers, chemists, metallurgists, and technicians. These scientists and engineers, working with previously acquired equipment and with many new facilities, began a concerted applied research and developmental effort toward such goals as the development of a successful volume-production power transistor. Formalizing of this semiconductor work, which had been the object of continued study by individuals in the Engineering Department for a number of years, brought a renewed interest in the fundamentals of electron theory. The literature in the electron theory field has grown rich—and voluminous—since C. J. Stoney conceived the name "electron" in 1874. Among the works which drew new interest at Delco Radio were Hall's 1879 theories on free electrons, Lorenz' postulation of the existence of electrons, Drude's and Lorentz' explanations at the turn of the century of free electrons in metals, Dunwoody's and Pickard's independent discovery of crystal detectors in 1906, Fleming's patented vacuum tube of two years earlier, and De Forest's triode of 1907. Heisenberg's 1928 publications concerning "holes" in solids also drew attention, as did a host of modern publications and developments in semiconductors and, specifically, transistors. These studies, combined with Delco Radio's own experimental work, formed the informational base on which to embark on new developmental work in the new semiconductor laboratory.

The science of the electron is an exemplification of the advantages gained when theory can be confirmed by observation and particularly when confirmation can come through the sense of sight. For example, of these smallest particles of electricity postulated[1,2] to exist in all nature, those in space were studied, discovered, and measured before 1900[3]. In solids, however, their presence remained a hypothesis although, then, a substantially proven one. Little else was learned about them until the concept[4,5] that metals like copper conduct current by means of the electrons in these solids. This theory was not perfected or supported for some time[6]. Also, the means by which the semiconductor crystal detector[7] of early radio conducts more current of one polarity than that of the other was not understood until about 26 years ago[8].

Therefore, because of the better knowledge due to the more readily observable effects, the development of electrons-in-space devices advanced rapidly. At first, and at the time of the early crystal detector, these were, like the crystal detector, diodes[9] These vacuum or gas tubes not only rectify, as does the crystal detector, but also—in various other later forms—produce light from electricity, conduct electricity when subjected to light, or conduct electricity when subjected to heat.

Electronics—The Vacuum Tube

But the science of the electron really began, or at least its impetus began, when the vacuum tube, in which a third element had been added to those of th diode to control the electron stream came into use about forty years ag It was then that this science was name "electronics" and its history and progre have been those of the vacuum or ga tube. The popular concept now is th electronics *is* the vacuum tube or it applications.

This vacuum tube, invented[10] abou eight years before it came into use, is triode since it has three active elemen the diode elements—which are th cathode, the emitter of the electrons, a the anode, the collector of them—an the added grid, interposed in the electro stream to control it. Thus, an electr static amplifier is provided since a extremely small amount of power in th grid or input circuit controls a ver much larger amount of power in th anode or output circuit. Although ther are a number of types of amplifier available, such as hydraulic or magneti ones, none has such a low inertia controlled lever as is the electron stream Because of this, only the electron tube i able to sense, follow, and function o variables with extremely high rates o change. Standard diode, triode, and pentode vacuum tubes operate on several hundred megacycles per secon frequencies, for example, ultra-high-fre-

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[1] C. J. Stoney invented the name "electron" in 1874. Reference: Hoag, J. Barton, *Electron and Nuclear Physics* (New York: D. Van Nostrand Co., Inc., 1942), p. 1.

[2] In 1880 L. Lorenz postulated the existence of the electron. Reference: Burton, E. F. and Kohl, W. H., *The Electron Microscope* (New York: Reinhold Publishing Corp., Inc., 1942), p. 74.

[3] Sir J. J. Thomson discovered and measured the electron in space (1897). Reference: Happell, George E. and Hesselberth, Wilfred M., *Engineering Electronics* (New York: McGraw-Hill Book Company, Inc., 1953), p. 1.

[4] Drude, P., "Zur Elektronentheorie der Metalle," *Annalen der Physik*, Vol. 1—irregular (1900), pp. 556-613.

Hall, E. H., "On a New Action of the Magnet on Electric Currents," *American Journal of Mathematics* (Quarterly), Vol. 2 (1879), p. 287.

[5] Lorentz, H. A., *The Theory of Electrons* (Leipzig: Treubner, 1906) and (New York: G. P. Stechert and Co., 1923).

Lorentz, H. A., "The Motion of Electrons in Metallic Bodies," K. Akademie van Wetenschappen, Amsterdam. Afdeeling voor de wis-en natuurkundige Wetenschappen. *Proceedings of the Section of Sciences*, Vol. 7 (1905), pp. 438-53, 585-93, 684-91.

[6] Sommerfeld, A., "Zur Elektronentheorie der Metalle auf Grund der Fermischen Statistik," *Zeitschrift für Physik*, Vol. 47 (1928), pp. 43-63.

[7] In 1906 General H. C. Dunwoody discovered th silicon carbide crystal detector. In the same year G. W. Pickard discovered the lead sulphide crysta detector. Reference: Archer, Gleason L., *History o Radio to 1926* (New York: The American Historica Society, Inc., 1938), Sec. 58, pp. 90-91.

[8] Wagner, C. and Schottky, W., "Theorie de geordneten Mischphasen," *Zeitschrift für Physikalisch Chemie*, Vol. 11b (1930), p. 163.

[9] Sir J. A. Fleming patented the diode vacuum tube i 1904. Reference: Happell, George E. and Hesselberth, Wilfred M., *op. cit.*, p. 1.

[10] The triode was invented in 1907 by Lee De Forest Reference: Ryder, John D., *Electronic Fundamentals an Applications* (New York: Prentice-Hall, Inc., 1950), p. 2

By **BERTRAM A. SCHWARZ**
Delco
Radio Division

A chief engineer views a new field in light of old theories

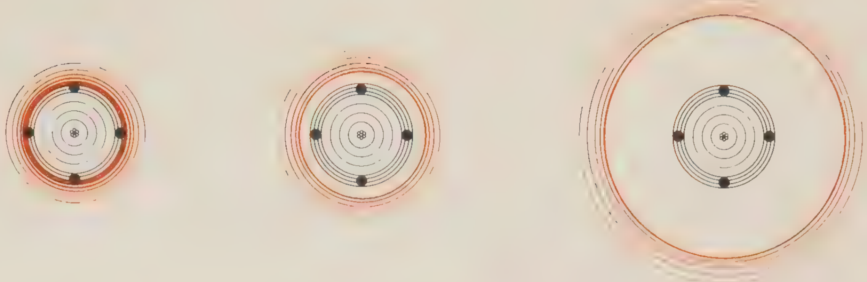

Fig. 1—Each of these single-atom diagrams of these solid materials shows four valence electrons which are bonded to those of neighboring atoms, forming valence bonds. In these solids, the outer energy levels, shown in color, form *conduction bands.* The gaps between the valence and conduction bands are *forbidden zones.* The presence and size of these zones are determinants of resistance and its converse, conductance.

quency television. The Magnetron and articularly the Klystron tubes work on requencies very much higher than this.

This ultra-high-speed operation is the rincipal ingredient in systems which etect and, while following, compute—hat is, analyze, memorize, and predict—nd then act on the resultants to provide ervices such as guidance of missiles, adar location, tracking, and gun sight-ng and direction. For such military ses, the accomplishments outweigh the omplexity and the maintenance needs f these systems.

Despite this knowledge, these prin-iples are not applied extensively to ivilian uses. For example, they con-eivably could find widespread use for more effective automatic control of light-ng, heating, cooling, and ventilating. In vehicles such as the plane or the automobile, there are the many additional variables, due to or associated with their motion, to be handled. In these vehicles, electronics not only can provide communication and the determination of location, path, and road conditions, but also electronics can act to control the variables of the power plant, for example, the ignition, fuel, air and water, and those of the transmission, traction, steering, braking, ride, lighting, and electrical system. Such civilian uses, at present, are restricted largely because the accomplishments do not justify such systems' complexity and maintenance needs. Technological advances—such as to higher speed and larger planes and the handling of more of them—continue to increase the need for and the use of electronic automatic aids. At the same time, electronic improvements continue to increase the ratio of accomplishment to complexity and maintenance needs.

With these as objectives, the Delco Radio Division military and civilian engineering work not only consists of circuit and vacuum tube improvements but also considerations of other implements such as the relatively new transistor. These semiconductor studies of more than six years and the more recent laboratory experiences developing experimental transistors have provided the material for the following survey.

Before proceeding, consider that the electron tube is the employment of polarized (negative) conduction, that is, negative particles of electricity, electrons, in space, flowing toward the positive pole.

Electrons in Solids

As mentioned, the science of the electrons in solids had not progressed because of the difficulty in confirming concept by experimentation. First knowledge was of conduction by the valence electrons—those in the outer shells of the atoms of the material (Fig. 1); therefore, negative conduction like that of the vacuum tube. These valence electrons are bonded to those of the neighboring atoms, forming a lattice structure. This covalent bonding results in the material, as a unit, having various energy bands, the outer of which provides conduction if empty except for a few electrons. A material which is a conductor has its conduction and valence bands overlapping. A material which is an insulator, however, has a considerable gap between its conduction and valence bands. This gap is termed a *forbidden zone.* A very considerable amount of energy would have to be imparted to the electrons of the valence band to have them reach the conduction band. The

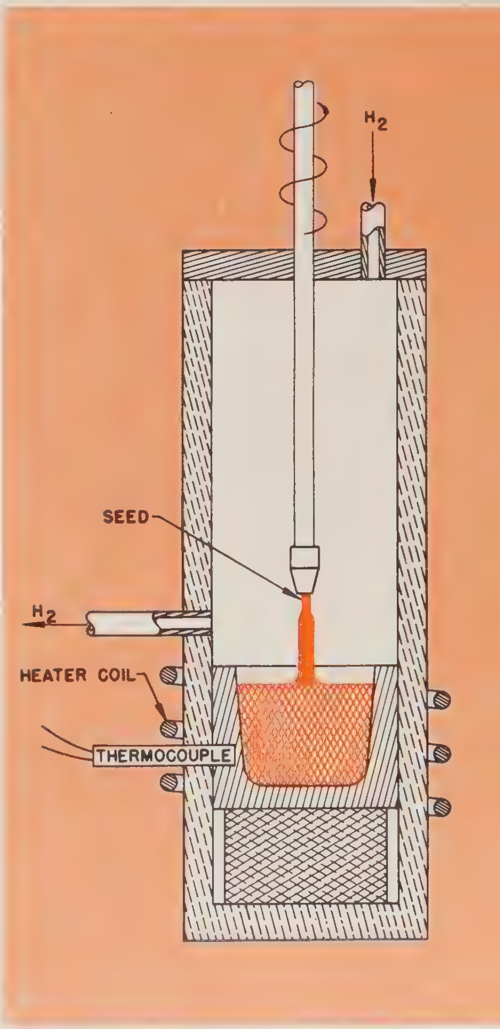

Fig. 2—Crystal growing is the conversion from a poly-crystalline to a single-crystal structure. In a highly purified hydrogen atmosphere within a quartz tube, the germanium melt temperature is accurately controlled. In this melt is dipped a properly oriented single crystal seed. As the seed is extracted and usually rotated, a long, single crystal of germanium grows onto it.

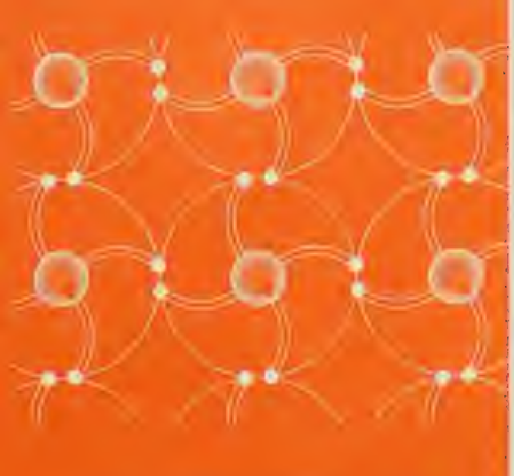

Fig. 3a—Intrinsic germanium at 0° K has no free electrons; therefore, no conduction.

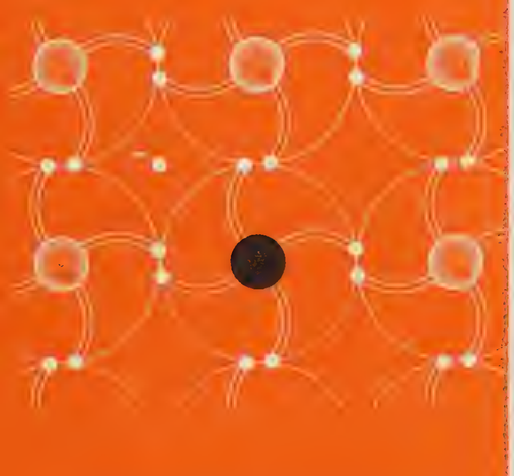

Fig. 3b—Donor or N-type germanium has an excess of free electrons; therefore, negative conduction.

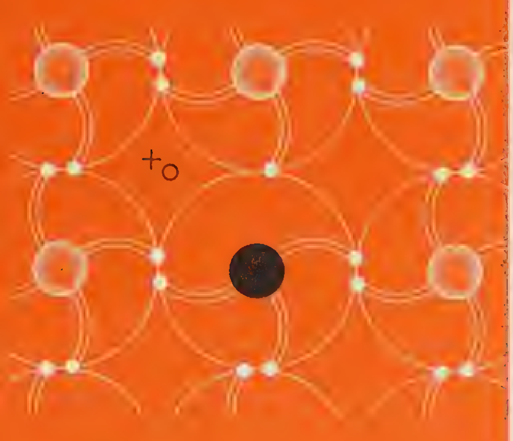

Fig. 3c—Acceptor or P-type germanium has a deficiency of electrons; therefore, holes—positive conduction.

Drawings show simplified representations of the atomic structures of intrinsic and extrinsic, N- and P-types, germanium.

third class of material is called a *semiconductor* because it falls between the conductor and the insulator. It is a conductor, though a relatively poor one, at high temperatures but an insulator at low temperatures. Its forbidden zone is smaller than that of the insulator so that less energy is required to excite the valence band electrons to have them reach the conduction band.

"Holes" as Well as Electrons in Solids— Positive and Negative Conductions

Although the existence of positive electrons called *positrons* had been known, these are so short-lived that they cannot be employed. Relatively recently, an important addition was made to the theoretical concept of conduction in solids[11]. This is of a device termed a "hole" which acts like a positive electron insofar as polarity is concerned but its mass and mobility are different. In a material having its valence bands filled with electrons except for a few vacancies, current conduction is provided by these vacancies or holes which move through the material when excited and this conduction is of the positive type as contrasted to that of the conduction by electrons which is of the negative type. These holes, therefore, move in the opposite direction to that of the electrons. The early crystal detector and the copper-cuprous oxide rectifier of 1926[12] employ this principle. An understanding of these semiconductor diode rectifiers' action in employing both positive and negative conductions within the device was existent in 1930. Other than this relatively little use and the employment of positive ions in electroplating, electricity with its branch, electronics, has been based on negative conduction. Even the ionized gases of neon, fluorescent, and other special tubes employ the ions merely to break down the gap. The conduction is by the electrons.

Microwaves Required the Return of the Semiconductor Crystal Diode

At the start of World War II, microwaves came into use for radar and radic The vacuum tubes then available eithe had too high an internal capacity or to long a path of travel of the electron that is, transit time of them, or both, t be satisfactory detectors of such extremel high frequencies. Although the vacuur tube, because it amplifies as well a detects, had previously displaced th diode crystal detector, the latter wa reintroduced for microwave detectio because of its low capacity. However, it reliability had to be improved and it criticalness eliminated. The early crysta detector was comprised of a semiconductor material most frequently of silicon, silicon carbide, or lead sulphide an the second element, a conductor lightl contacting the crystal at a sensitive spot This contactor, which was termed "cat whisker," had to be delicatel adjusted and frequently readjusted. Rectification takes place at the junction o the contactor and the crystal.

Research groups assigned by militar agencies to this task of improvemen chose for this work the semiconducto materials germanium and silicon becaus of their particular atomic lattice structures. Since it was known that th presence of even minute amounts impurities greatly alters the conductivi and behavior of these solids, the wo first involved perfection of processes f refining the material to an extremel high degree, one approaching the intrinsic—the absolutely pure—state. Next they introduced known minute quantities of known impurities to obtain both the degree and the type of conductivity desired, negative or positive. This work resulted in a high-sensitivity, high-frequency—but low-current-handling—semiconductor diode rectifier so stable as to permit the cat whisker to be fixed permanently to the crystal.

The Transistor— The First Triode Semiconductor

About six and one-half years ago, the transistor was announced[13]—the first electrons (and holes) in solids, semiconductor triode—the first solids device capable of controlling, manipulating, and amplifying as does the multi-element vacuum tube, but which accomplishes these things in a somewhat different manner. The vacuum tube operates by

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[11] Heisenberg, W., "Zur Theorie des Ferromagnetismus," *Zeitschrift für Physik*, Vol. 49 (1928), pp. 619-36.

Heisenberg, W., "Zum Paulischen Ausschliezungsprinzip," *Annalen der Physik*, Vol. 10 (1931), pp. 888-904.

Wilson, A. H., *Semiconductors and Metals* (England: Cambridge University Press, 1939), p. 77.

[12] Grondahl, L. O. and Geiger, P. H., "A New Electronic Rectifier," *Transactions of the A.I.E.E.*, Vol. 46 (1927), pp. 357-66, (also *Journal of the A.I.E.E.*, Vol. XLVI (January-December 1927), pp. 215-22).

[13] Bardeen, J. and Brattain, W. H., "The Transistor, A Semiconductor Triode," *The Physical Review*, Vol. 74, No. 2 (July 15, 1948), pp. 230-31.

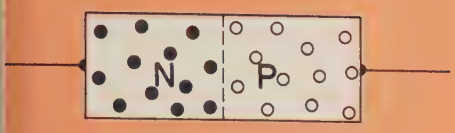

Fig. 4a—In this equilibrium condition shown, no potential is applied.

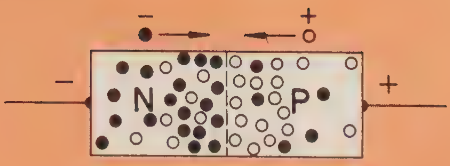

Fig. 4b—When polarized in the forward direction, as shown, maximum conduction occurs.

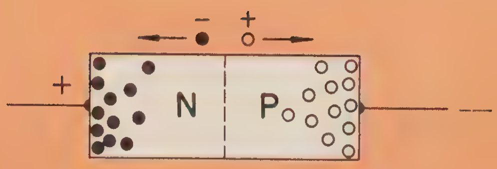

Fig. 4c—When polarized in the backward direction, as shown, little conduction takes place.

The actions of electrons and holes at **N-P** junctions determine the conductivity of junction-type transistors.

means of a controlled stream of electrons—negative conductivity. This transistor operates by means of controlled electrons and holes—negative and positive conductivities.

Point-Contact-Type Transistor

The first transistor later was classed as a point-contact type. This consists of two closely adjacent, pointed conductors contacting a small wafer of the semiconductor, germanium crystal. The two contactors, plus an ohmic connection to the crystal, are the connections to this triode. Thus, it would appear that the transistor came into being by the addition of one pointed contactor or cat whisker to the early crystal detector diode, but this is an oversimplification. One of the transistor's two contactors is termed the *emitter;* the other, the *collector;* and the crystal with its ohmic connection is the *base*. The input of the point-contact type is usually between the emitter and the base, and the output is between the collector and the base.

The germanium crystal of the transistor is highly purified by the *zone refining process* which consists of successive heating stages sweeping the impurities to one end of the ingot because the solubilities of the impurities in the melted and the solid germanium are different. This high impurity end is chopped off and the process repeated until the germanium has only *one* impurity atom for each *billion* germanium atoms. Now, the germanium is too pure since the transistor action occurs because of controlled crystal imperfections. Also, at this stage, the germanium is of a poly-crystalline form with a varied distribution of crystal boundaries. The germanium must be a *single* crystal so that its atoms' lattice structure is properly lined up and bonded for satisfactory movement of the electrons and holes. The conversion from poly-crystalline to single-crystal form is accomplished by a method of crystal growing such as the Czochralski method (Fig. 2). This consists of inserting a properly oriented single crystal seed into a closely maintained temperature germanium melt, in a purified hydrogen atmosphere, within a quartz tube. As the seed is slowly extracted and usually rotated, the germanium grows onto it in a long, cylindrical, single crystal form.

In the melt from which the crystal is grown is added the small quantity of one type impurity which determines whether the conductivity of the crystal will be of the **N** or the **P** type. About one millionth of a gram of impurity is added to 100 grams of the crystal.

Fig. 3 represents, in simplified form, the atomic structures of: intrinsic germanium (Fig. 3a); germanium of the **N** type (Fig. 3b); and germanium of the **P** type (Fig. 3c).

Intrinsic or Pure Germanium

In Fig. 3a, representing intrinsic germanium, it is shown that each germanium atom has four valence electrons—those in the outer shell of the atom. Each of these four negative charges is locked fast to those of the neighboring atoms. At low temperatures, none of the valence electrons are free to move about but, at higher temperatures, some are unlocked. In the latter condition, the material is a conductor of current, though a poor one.

Donor or N*-Type Germanium*

Fig. 3b represents intrinsic germanium, which has a valence of 4, to which has been added a minute quantity of a material such as antimony, having a valence of 5, that is, five electrons in the outer shell of each of its atoms. Then, the material has a surplus of electrons. These excess electrons provide negative conduction.

Acceptor or **P**-*Type Germanium*

Fig. 3c indicates intrinsic germanium doped with a minute quantity of a material such as indium, having a valence of 3 as contrasted to the germanium of valence number 4. Then, there will be electron deficiencies or holes in the crystal structure and, as previously mentioned, these holes provide positive conduction. The holes flow in the opposite direction to that of the electrons.

Junction-Type Transistor

About a year after the first transistor was announced, a second, called a junction type, was introduced[14]. It consists of two sections of semiconductors of one polarity conductivity separated by a central section of semiconductor of the opposite polarity conductivity; thus, it can be **N-P-N** or **P-N-P**.

Whereas, in the point-contact-type transistor, rectification takes place at the points of contact to the crystal, in the junction type, the action takes place at the junctions between each section. Each of these triodes is, in reality, two diode rectifiers, back to back. Fig. 4 indicates the action of the electrons and holes at the junction of **P**- and **N**-type semiconductors. Fig. 4a indicates the condition of the junction at equilibrium. In Fig. 4b, the junction is biased in the forward direction causing current conduction. In Fig. 4c, the junction is biased in the backward direction. Then, there is but little flow of current.

Grown Junction Transistor

The first of these junction-type transistors was produced by the crystal growing process with the sections alternately changed from one conductivity type to the other by controlling the impurity

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[14] Shockley, W., "The Theory of P-N Junctions in Semiconductors and P-N Junction Transistors," *Bell System Technical Journal*, Vol. 28, No. 3 (July 1949), pp. 435-89.

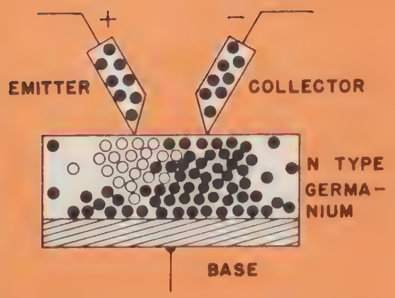

Fig. 5a—In this point-contact-type transistor diagram, the emitter bias is positive and the collector negative with respect to the base.

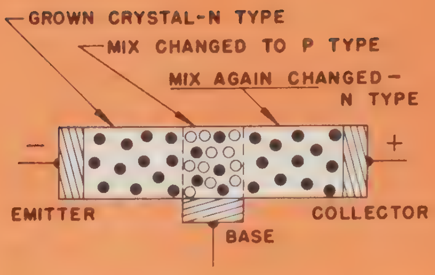

Fig. 5b—In the grown junction-type transistor with **N-P-N** polarities, the emitter bias is negative and the collector positive with respect to the base.

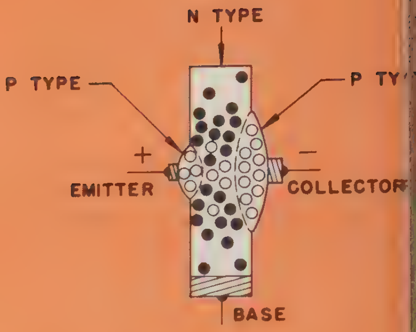

Fig. 5c—The alloyed junction-type transist with **P-N-P** polarities is biased like that of th point-contact type of Fig. 5a.

The point-contact, grown junction, and alloyed junction types of transistor are shown diagrammatically. In all three of these, the emitter-base diode portion is biased forward for maximum conduction and the collector-base diode portion is biased backward for minimum conduction.

injections as the crystal is being grown. This is a difficult process particularly considering that the central section, the base, of each complete triode must be a very small one.

Alloyed Junction-Type Transistor

Later, the alloyed junction-type transistor was developed[15]. Here, a properly doped central or base section semiconductor has added to it the two outer sections, the emitter and collector, respectively, by means of alloying. These two outer sections are of suitable alloy material to start with, usually of indium germanium. The present alloyed junction-type transistors are mostly of the **P-N-P** type.

Transistor Action

Amplification by the transistor depends upon the phenomenon of controlled injection of so-called minority carriers at the emitter junction, that is, the junction between the emitter and the base. Therefore, to provide this injection, the diode portion, comprised of the emitter and the base, is biased in the forward-current direction so that the resistance of this section is relatively low (Fig. 4b). The collector and base diode portion of the transistor is biased in the reverse current direction, making its resistance higher than that of the input (Fig. 4c).

Fig. 5 indicates, diagrammatically, the action of transistors of the point-contact type (Fig. 5a); that of the grown junction type (Fig. 5b); and that of the alloyed junction type (Fig. 5c). The point-contact type has the crystal or base of **N** conductivity. The grown junction transistor shown is of **N-P-N** polarities and the alloyed junction type is of **P-N-P** polarities.

Fig. 6 shows three possible connections of the triode transistor as compared with three basically similar connections of the triode vacuum tube and some of the formulae involved.

Transistor Status

In the six and one-half years since its announcement, the transistor has received a great amount of publicity—perhaps disproportionate to its actual accomplishments to date, but justifiable because of its great future promise. It adds to the accomplishments of the family of electrons-in-solids devices some of the most important ones of electrons-in-space devices. Electronics is given more than just another implement, for the transistor has characteristics different from the vacuum tube, enabling it to perform new tasks or some of the present ones better. They are, thus, a complementary pair.

The size and weight of the low-power transistor are so minute as to lead the imagination to the cartoonist's concept of a wrist watch radio. However, other components, such as the tuner, transformers, and loudspeaker of a radio set and the viewing tube also of a television set, are the principal determinants of overall size and weight. In some instances, the components used with the transistor will be larger but more often smalle and some will be eliminated. For example, its low impedance often requires th use of a transformer in place of the smal low cost resistor and condenser couplin network frequently employed in certai vacuum tube circuits. Because of thi low impedance, high-capacity by-pas and filter condensers are necessary. O the other hand, these condensers can of low-voltage construction in contras to those in the vacuum tube's hig voltage circuits. Then, for portable equi ment powered by a battery, the latte can be much smaller. Also, for power li operation, no high-voltage power suppl is needed with the transistor.

The current drain is extremely lo partly because this semiconductor ha no filament. About one-half of the tota power consumption of smaller vacuum tubes is that of the filament, to heat th cathode. The energy taken by the filament alone is frequently many thousan times that of the energy on which wor is performed. Reduction in size an handling power of a tube is limited by the fragility of the filament and othe elements. Not having these fragile elements, very light service transistors whic consume only about 10 mu w of power have been made. Present larger unit have power consumptions one-fifth t one-twentieth that of vacuum tubes fo comparable service. A recently develope experimental 12-v automobile radio completely transistorized, consumes les than one-fifth the power of a comparabl vacuum tube set. Low current drain is o particular value in small, portable devices such as the hearing aid, for th battery size and weight then can b much less and/or its life greatly prolonged. These savings in battery size, weight, and cost are also the principal reasons why even the present high-cost transistor is well adapted technically and economically to use in the hearing aid. The low current drain also qualifies it for applications where a "keep-alive" device is essential or desirable.

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[15] Law, R. R.; Pankove, J. I.; Mueller, C. W.; and Armstrong, L. D., "A Developmental Germanium P-N-P Junction Transistor," *Proceedings of the I.R.E.*, Vol. 40, Part 2 (July-December 1952), pp. 1352-57.

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No filament not only means there is not this power consumption but also there is then no warm-up time. This is of value if the device is used in applications where it is switched off and on and immediate operation is necessary or desirable when it is switched into action.

The ruggedness of the transistor, since it has no closely spaced assemblage of fine elements, means freedom from the microphonism of the vacuum tube. The junction type, particularly, is a solid unit which can withstand extremely severe shocks—said to be as great as 20,000 *g*'s.

Positive as well as negative conduction provided by the transistor contributes to its versatility. Networks, transformers, or other arrangements for phase inversion, thus, may be avoided.

This current-operated, low-impedance current amplifier, the transistor, is particularly suited to use in vehicles which have low-voltage electrical systems. Because it is current-operated, rather than voltage-operated as is the vacuum tube, it will work directly from such an electrical system and not require a high-voltage power supply. Also, being of low impedance and a current amplifier, it is better suited than the high-impedance, voltage-amplifier vacuum tube to couple into low impedance, power- or current-operated devices such as relays, servomechanisms, and loudspeakers. On the other hand, the vacuum tube would seem to be better suited to operation on weak impulses composed principally of voltage. However, the vacuum tube has had to be used disadvantageously as well as advantageously. It may be, because of certain other controlling conditions such as that of low-voltage operation, that the present type transistor will be used even for voltage amplification and, thus, somewhat disadvantageously.

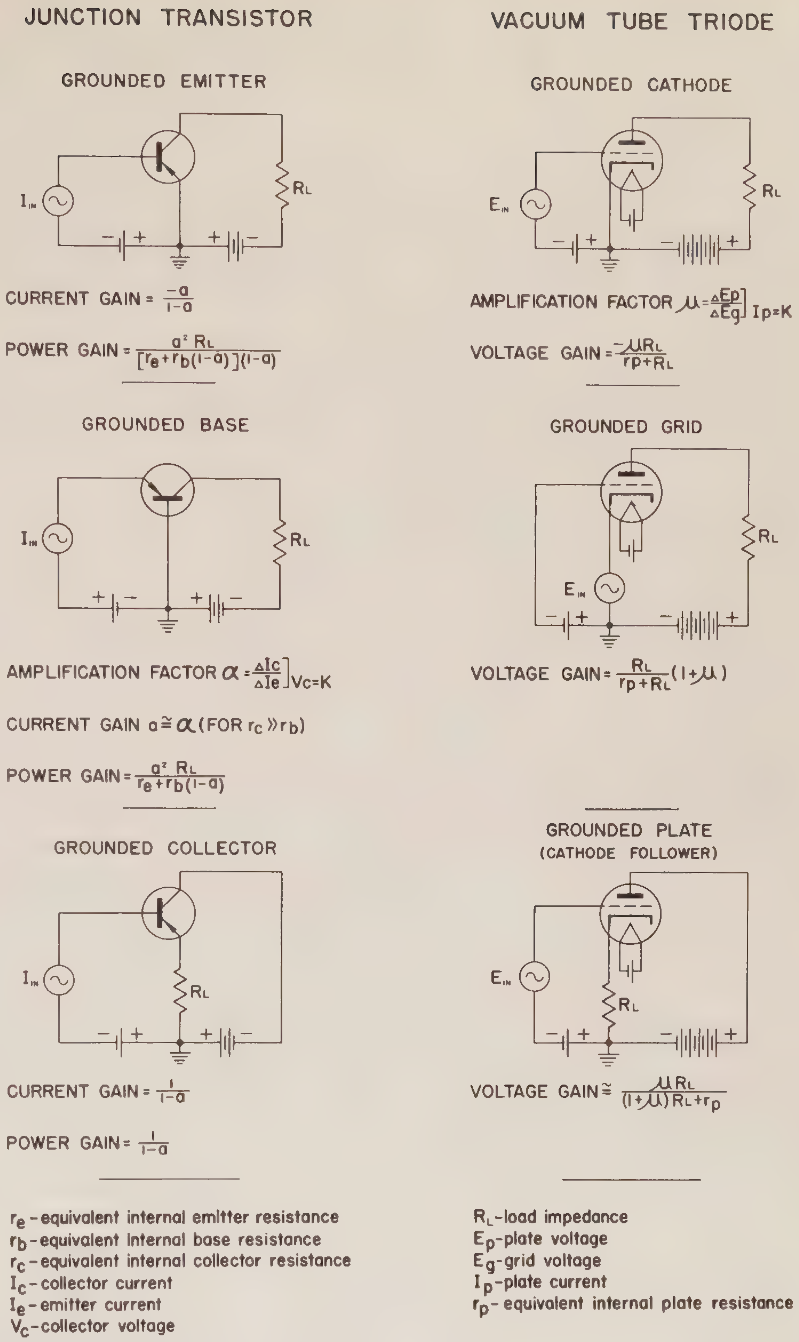
JUNCTION TRANSISTOR
VACUUM TUBE TRIODE
GROUNDED EMITTER
I_{IN}
R_L
CURRENT GAIN = $\frac{-a}{1-a}$
POWER GAIN = $\frac{a^2 R_L}{[r_e+r_b(1-a)](1-a)}$
GROUNDED CATHODE
E_{IN}
R_L
AMPLIFICATION FACTOR $\mu = \frac{\Delta E_p}{\Delta E_g}\Big]_{I_p=K}$
VOLTAGE GAIN = $\frac{-\mu R_L}{r_p+R_L}$
GROUNDED BASE
I_{IN}
R_L
AMPLIFICATION FACTOR $\alpha = \frac{\Delta I_c}{\Delta I_e}\Big]_{V_c=K}$
CURRENT GAIN $a \cong \alpha$ (FOR $r_c \gg r_b$)
POWER GAIN = $\frac{a^2 R_L}{r_e+r_b(1-a)}$
GROUNDED GRID
E_{IN}
R_L
VOLTAGE GAIN = $\frac{R_L}{r_p+R_L}(1+\mu)$
GROUNDED COLLECTOR
I_{IN}
R_L
CURRENT GAIN = $\frac{1}{1-a}$
POWER GAIN = $\frac{1}{1-a}$
GROUNDED PLATE
(CATHODE FOLLOWER)
E_{IN}
R_L
VOLTAGE GAIN $\cong \frac{\mu R_L}{(1+\mu)R_L+r_p}$
r_e - equivalent internal emitter resistance
r_b - equivalent internal base resistance
r_c - equivalent internal collector resistance
I_c - collector current
I_e - emitter current
V_c - collector voltage
R_L - load impedance
E_p - plate voltage
E_g - grid voltage
I_p - plate current
r_p - equivalent internal plate resistance

Fig. 6—Three possible transistor and basically similar vacuum tube connections and applicable formulae are compared.

Frequency, noise, and amplification limitations are being lifted rapidly. A new transistor type called the *intrinsic barrier*[16], recently announced, operates on frequencies as high as 440 megacycles per second and has a theoretical limit, at present, of 3,000 megacycles per second. Early point-contact- and junction-type designs were troubled with high internal noise but the latest designs, particularly those of the junction type, compare favorably with the vacuum tube. The present power gain maximum of about 40 db is considerably below that of vacuum tubes. Also, at present, there are no dual types such as the diode/triode, dual triode, and pentagrid converter vacuum tubes.

The heat limitation of germanium seemed to restrict operation of semiconductors of this material to ambient temperatures of 50° C. Power types had to be operated in lower ambient temperatures than this or had to be greatly de-rated because of their own joule heating. Most transistor research and development has been done with germanium. Until late

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[16] Early, J. M., "P-N-I-P and N-P-I-N Junction Transistor Triodes," *Bell System Technical Journal*, Vol. 33, No. 3 (May 1954), pp. 517-33.

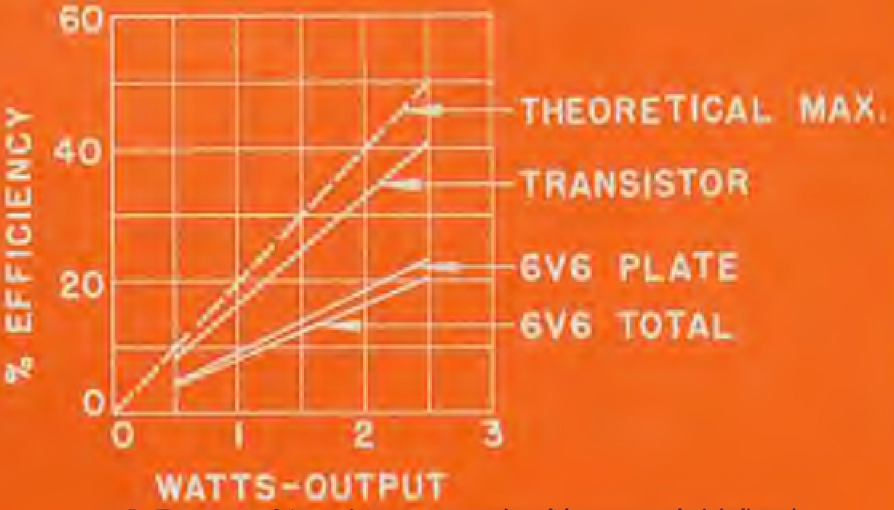

Fig. 7—The greater efficiency of the transistor to that of the vacuum tube is indicated by these curves of an experimental power transistor and a standard power vacuum tube, both operated in Class A, without degeneration.

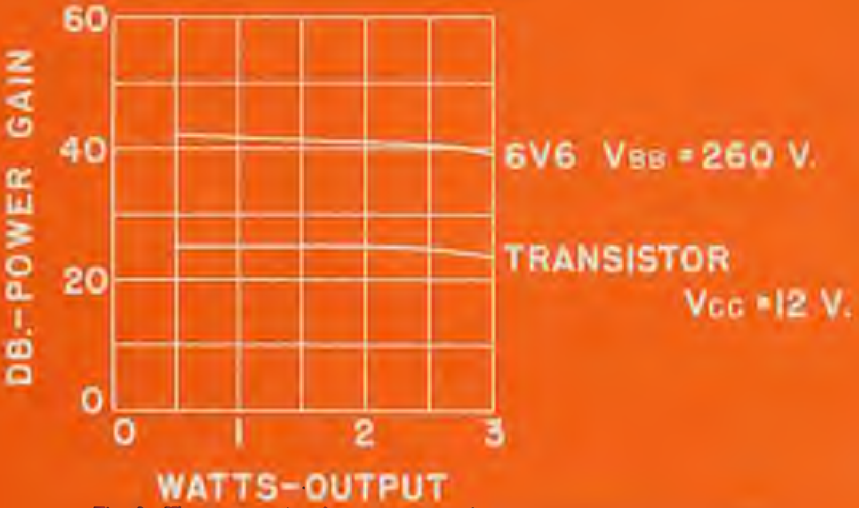

Fig. 8—The power gain of an experimental power transistor operated below its optimum voltage is shown to be lower than that of a standard power vacuum tube—again, both operated in Class A, without degeneration.

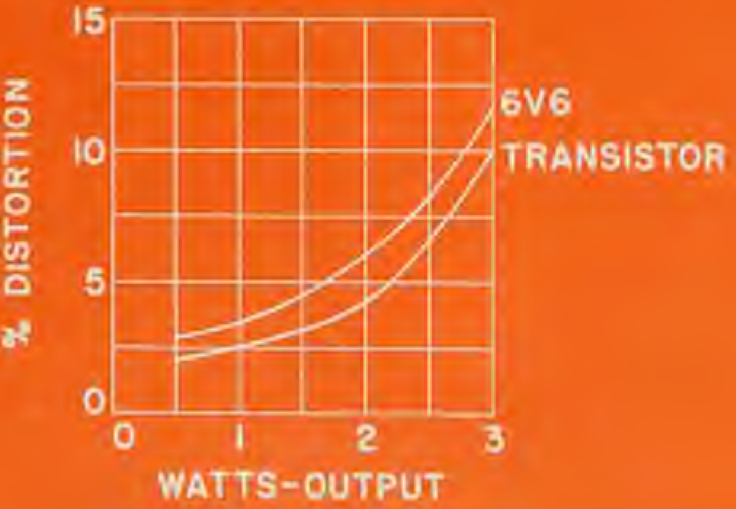

Fig. 9—New techniques have lowered the harmonic distortion of an experimental power transistor to values below those of a standard power vacuum tube. The curves are for Class A operation and no degeneration.

1953 it appeared that silicon or an alloy of silicon and germanium or intermetals such as aluminum/antimony would have to be used to solve the problem. But less is known of these other materials and they introduce far greater problems of refining, alloying, and processing. It is much more difficult to obtain with silicon, for example, satisfactory lifetimes of injected minority carriers for suitable, amplifying transistors.

Power-type transistors of germanium have been produced with the elements of adequate size and one of these directly connected to a suitable heat sink. These units operate in ambient temperatures as high as 80° C and handle 20 w of power. They satisfactorily handle this power in applications where change in gain with input change is not important. However, they have to be de-rated greatly in power handling as amplifiers of sound, for example, where the linearity of output to input relationship must be maintained to avoid distortion of wave form. This difficulty is due to the change in *alpha*, the current amplification factor of a transistor. Recent work has revealed techniques for flattening this alpha characteristic with variations in input while preserving appreciable power amplification and handling. Figs. 7, 8, and 9 show performance characteristics of some fairly recent, experimental power transistors of this type.

The reproducibility, reliability, and life potentials remain to be determined. It is estimated that the total number of transistors made for use other than laboratory, since the start of production about two and one-half years ago, is of the order of magnitude of two million units. It is estimated further that more than 90 per cent of this production was for hearing aids and, therefore, low-frequency, low-power types. The next largest use was of these types in simple computer service such as punched card, telephone route switching. As a contrast, vacuum tubes of all types, including the 15-year old subminiature, are being made in quantities of about four-hundred million per year and were produced first in early multi-element form about forty years ago. The present methods of manufacturing transistors still are very much those of the laboratory. Production shrinkage is much higher than that of the average, more complex, higher performance vacuum tube. There is insufficient knowledge, production experience, and quantity requirement to introduce automatic, continuous chemical and metallurgical processing and testing which can be visualized.

Most of the transistors produced are inbedded in plastic casings with lead seals of glass. The excessive first year service troubles originally were thought to be due to moisture, for the germanium surface is very sensitive to this. Later, it was reported that the difficulty was caused by poor internal connections. During the past one and one-half years, the field troubles have been as low as those of the subminiature tube it replaced in hearing aids. This is lower than the average and, as mentioned, more complex vacuum tube. Therefore, the plastic encasement design seems to be satisfactory for this service and its cost is low. For more rigid requirements, encapsulation in metal or glass and a vacuum are indicated.

Theory points to a semiconductor life expectancy of 70,000 hr. Despite limited knowledge and production experience, lack of controlled processing and quantities of manufacture, considerable progress has been made toward this goal. The present units are believed to have considerably longer life than the vacuum tube.

For these reasons also, even the lowest cost transistor, at present, is more expensive than the subminiature tube it replaces in the hearing aid, but there are compensating savings in batteries. Also, this transistor is almost eight times the cost of the average high-production vacuum tube. Although its use in many instances will bring about savings in other components, these frequently will not pay for its high cost. As an example, in an automobile radio, if transistors are used throughout, the high voltage power supply, comprised of a vibrator, transformer, rectifier, and electrolytic condensers, will be eliminated. The cost of this power supply is about the same as or slightly less than that of the present lowest cost transistor. Since, as previously stated, these do not provide the degree of amplification of the vacuum tube, nor are they available in dual units, additional transistors are needed in a circuit to obtain equal performance. However, reliability, ruggedness, length of life, low current drain, and accomplishments will qualify transistors of even greater than present cost for applications not open to the vacuum tube.

Other Types of Transistors and Semiconductor Devices

The more immediate predecessors of the transistor than the crystal detector diode mentioned previously are the thermistors and varistors. These are semiconductor devices providing control of conduction by means of electrons-in-solids, with temperature or with voltage or current variations. Then, there are the electrons-in-solids photocell devices, the photo-conductors and the photo-diodes which, when subjected to the photons of light, produce a current conduction or emission change. In the instance of the photo-diode, light is the third element making this device, in effect, a triode since the light strikes an internal element directly and does not require a separate element to inject it. Then, there are the photo-transistors which behave like the photo-diode and have a built-in stage of amplification due to the extra section.

The multi-element vacuum tube has advanced from the triode to the tetrode, the pentode, the heptode, and to many other forms of multi-elements but it has not become a current-operated nor a low-impedance device and it does not work on positive conduction. The transistor, although now a triode, promises to be brought out in many other forms such as tetrodes and pentodes but here, the additional elements will have other functions from those of the additional elements of the vacuum tube. For example, the element making the vacuum tube a tetrode from a triode is a screen grid interposed between the input and the output circuits, This serves to prevent unwanted feedback. The vacuum tube is a high-impedance device. When the frequency is high enough for the capacitance path between the input and output elements and when the voltage gradient between these elements is great enough, feedback results without this screen grid. A fourth element may be added to the present transistor for control purposes, for example, rather than for stability.

The present transistor is a *bi-polar* device—it operates on both negative and positive conductions—but a *uni-polar* type[17] has been proposed and a few of them have been made experimentally. This type operates like the vacuum tube, on one polarity conductivity only, and the control element varies the stream in the same manner as does the grid of the vacuum tube. Such a device is a voltage amplifier of higher than normal transistor impedance although operated on low voltage. As well as uni-polar, this design is also referred to as an analogue-type because of its similarity to the vacuum tube. Then, there is the Fieldistor which, like the vacuum tube, is of high impedance, a voltage amplifier, and voltage operated. All of these are of the general family variously called, double base, uni-polar, and field effect. It is evident that innumerable types and variations will appear.

Conclusion

The transistor has made remarkable strides because of the great background of theoretical knowledge fairly recently confirmed by practical experimentation, coupled with the very considerable knowledge of electronics and modern physics in general, which was not available to the early vacuum tube experimenters. All of this knowledge, however, has a retarding effect toward the finalizing and processing of a few designs for, as these phases are about to be undertaken, new techniques and possibilities come to light. Also, transistors, of course, must compete now with a well developed device, the vacuum tube, which provides high standards of performance although perhaps not as high standards of reliability, ruggedness, and length of life as required for some services.

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Notes About Inventions and Inventors

If we but look about us, wherever we may be, our eyes constantly behold some article of manufacture that has form or shape and some aspect of beauty Just about every article of manufacture offered for sale today, be it a watch or an automobile, is arrayed in its finest garb to attract the greatest number of buyers. Design is paramount today with manufacturers of consumer goods because it is the distinctiveness and aesthetic appeal of one design over another that largely directs the impulse of a buyer to select the product of one manufacturer over the product of another that is perhaps of equal quality but of less beauty.

The design or appearance of a manufactured article is of interest to patent attorneys and to engineers alike because such designs are subject to protection under the patent laws. The Patent Statute says:

> "Whoever invents any new, original and ornamental design for an article of manufacture may obtain a patent therefore,—."

What Is a Design?

The essence of a *design* resides in the configuration or ornamentation which gives to an article of manufacture a new and distinctive appearance from other like articles of manufacture. If the design embraces outline only, no change in decoration will disturb its identity unless the apparent configuration of the article be also changed. If the design relates to the adornment of an article of manufacture of some known external form, the form may be indefinitely varied and yet the design of the ornament remains the same. When configuration and adornment, both being new, enter into the same design, a change in the necessary attributes of either changes the essence of the whole design.

The acts of Congress which authorize the grant of patents for designs are plainly intended to give encouragement to the decorative arts. They contemplate not so much utility as appearance. In fact, a design need have no utility so long as the design of the article of manufacture is new. The thing invented or produced, for which a design patent is given, is that aesthetic something which gives a peculiar or distinctive appearance to the article. The appearance may be the result of peculiarity of configuration, or of ornamentation, or of both conjointly.

A Patentable Design Must be New

A design invention, just like a mechanical invention, calls for the existence of novelty and the exercise of ingenuity which exceeds the skill of the normal workman in a given field. That is, the design creation must be the product of inventive skill and the exercise of inventive faculty. In the field of the mechanical patent, there must be novelty and utility; in the field of the design patent, there must be novelty and beauty.

The inventive designer, however, need not possess the skill of a great artist or sculptor, but he must possess more skill than that of the mere artisan applying the usual skill of his calling. A hard and fast rule or a set standard for determining in advance the degree of ornamentation and originality required to meet the test of patentability of a design in manufactured articles is no more possible in the law of designs than in mechanical inventions. The applicability of the design statute is as broad as the buying public's varying aesthetic tastes for new things.

But one thing is certain. In a design patent, as in a mechanical patent, the subject matter must be novel and must invoke an exercise of the inventive faculties. If either of these essentials is absent, the design patent cannot be sustained.

A Patentable Design Must be an Invention

While a design may be pleasing to the eye and may be commercially successful, nevertheless, the design patent may be invalid as lacking *invention.* The general overall distinctive effect of a design is that which is controlling in determining invention, rather than minor differences which may alter the design slightly from other like designs without changing the appearance of the design in the eyes of an "ordinary observer." Utility plays no part in determining the inventiveness of a design or the validity of a design patent. In fact, a showing of pure utilitarian purpose in the design, without any other basis for the design, is reason enough to render the design unpatentable or the design patent invalid.

Here again, just as in the patent law applied to mechanical patents, the element of what constitutes invention defies definition and resides as a subjective standard in the mind of the U. S. Patent Office examiner or the judge considered as an "average observer." What constitutes invention is always a perplexing question and difficult of solution—some courts holding that a high degree of inventive ability is necessary, something akin to genius, while other cases are to the effect that a lower degree of inventive ability will support a design than will support a mechanical patent. The only sure conclusion to draw is that each case, each design, must stand or fall on its own merits when compared with other like designs that have preceded it.

The validity of a design patent depends upon the same factors as that of a mechanical patent: (a) the condition of the art when the design was made, (b) how

By **DUWARD C. STALEY**
Patent Section
Dayton Office Staff

The mechanical patent: novelty and utility. The design patent: novelty and beauty.

ng the need had existed, (c) how nearly e art had approached the new design nd when, and (d) how far the design et with popular approval and displaced her designs when it appeared. But ppeal to aesthetic taste alone is insuffi-ent if invention is lacking. If the design oes no farther than to embody an bvious neatness and attractiveness that ill make articles of household use more ompact and pleasing than has generally een the case, this is not, in itself, enough.

To sustain a design patent there must e exhibited in the production of the esign an exercise of the inventive or riginal faculty as clear and of as high egree as is called for in patents for nventions or discoveries. In both, the nal production must have been en-endered by the exercise of brain power, nd to such an extent that it may be aid to be above the skill of the ordinary esigner—that is, one designing for func-onal form or shape with no other than tilitarian purpose in mind. The fact hat the functional and utilitarian shape may be extremely pleasing to the eye nd highly successful for commercial urposes is no criterion of patentable esign. If the shape could not be otherwise than as designed and still serve its urpose, the design is one of pure utility nd is not subject to protection under the esign statute.

Patentable Design Limited to Article of Manufacture

The design statute limits design pro-ection to any new, original, and orna-nental design for an "article of manu-acture." This is considerably more mited in its field of protection than that iven for a mechanical patent that in-ludes "any new and useful art, machine, manufacture, or composition of matter." It is the new and original design of an article that is made, manufactured, or produced—whether of metal, or of any other material, or of any combination of materials; a new or original impression or ornament to be placed on any article of manufacture; a new and original design for the printing of fabrics; a new and useful pattern, print, or picture to be worked into or on any article of manufacture; or a new or original shape or configuration of an article of manufacture that the design law has in view.

The Design Patent

While the design patent is similar to the mechanical patent in having applied to it many of the same legal philosophies in determining whether the particular design is patentable or is valid even if patented, it is different in its physical make-up.

In both the mechanical and the design patent, drawings are required to illustrate the invention, but the design patent drawings are in effect "works of art" to illustrate the special configurations created, whereas the mechanical patent contains many detailed mechanical cross-sectional drawing views.

In the design patent there is no lengthy detail description of the many component parts of the article of manufacture or of its mode of operation as in the mechanical patent, no description being allowed except in rare instances that are exceptions to the rule. And lastly, the one claim permitted in the design patent is intelligible to anyone reading the patent; it is "The ornamental design for a (name of article), as shown."

On this and the following pages are listed some of the patents granted to General Motors prior to September 30, 1954. The brief patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each patent.

Patents Granted

- **John E. MacArthur, Jr.,** *AC Spark Plug Division, Flint, Michigan, for a Carton Reclosure, No. 2,685,400, issued August 3.* This patent relates to a closure for a carton which is sealed by gluing the flaps together when the product is originally packaged and has specially constructed slots to permit easy opening and reclosing with interlocked flaps.

Mr. MacArthur is superintendent of the General Stores Division at AC Spark Plug. He joined the Division as a process engineer in 1939, following his graduation from University of Michigan with the B.S. degree in mechanical engineering. He was made supervisor of material control in 1943 and other promotions led to his present position in 1953. Some of his previous projects have included the development of expendable palletized shipments and studies of the effect and protection of cartons against humidity. This is the first patent granted as a result of his work in this field.

- **George W. Onksen, Jr.,** *Guide Lamp Division, Anderson, Indiana, for a Combined Reflector and Tail Light Lens, No. 2,685,231, issued August 3.* This is a combined tail lamp lens and reflector having a plurality of cube corner reflector units on the inner surface and a plurality of parallel flutes on the outer surface to bend and spread the reflected light.

Mr. Onksen is supervisor of research for Guide Lamp. He began his General Motors career in 1928 as an apprentice tool maker with Delco-Remy Division, also in Anderson. He attended General Motors Institute as a cooperative student of Guide Lamp and was graduated in 1933. In October of that year he was assigned to the Guide Lamp Engineering Department and immediately devoted his attention to solving vehicular lighting problems. He became a supervisor in 1936. His major contributions have been in the development of Sealed Beam headlamps and of automatic headlamp controls. His society affiliations include membership in the S.A.E.

- **Worth H. Percival,** *Research Laboratories Division, Detroit, Michigan, for an Expansible Fluid or Heat Engine, No. 2,685,173, issued August 3.* This invention relates to hot air engines in which standard heat exchangers are used in a novel circuit for a closed cycle engine. External heating and cooling is applied to the circuit and the engine is provided with valve

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

and compression means to control expansion and compression of the air in the closed circuit.

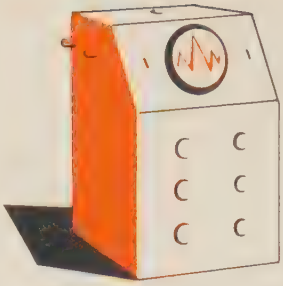
Mr. Percival serves as senior engineer —Diesel development in the Mechanical Development Department of the Research Laboratories. His career with Research began in 1947 as a junior engineer and in 1953 he was promoted to his present position in which he is currently concerned with the development of free-piston engine design. Most of Mr. Percival's previous projects have involved combustion research on two-cycle Diesel engines. Iowa State College awarded him the B.S. degree in 1942 and in 1947 he received the M.S. degree from Massachusetts Institute of Technology. Mr. Percival is a member of the S.A.E., A.S.M.E., and the honorary societies Tau Beta Pi and Sigma Xi.

- **Max P. Baker,** *Inland Manufacturing Division, Dayton, Ohio, for a Tread Construction, No. 2,686,697, issued August 17.* This patent deals with a removable tread construction for use with tank tracks and the like wherein the tread pad is interchangeable.

Mr. Baker is a project engineer in Inland's Engineering Department. His General Motors career began in 1924 with the Research Laboratories in Dayton, Ohio. In 1926 he transferred to the Oakland Motor Car Company as assistant superintendent of its Experimental Department. Three years later Mr. Baker left this post to engage in engineering work in the aircraft industry. In 1947 he came to Inland where he is currently engaged in developmental work on ball joints and tank tracks. Miami University granted Mr. Baker the A.B. degree in 1922. He is a member of the S.A.E. and the Institute of the Aeronautical Sciences.

- **John H. Diedring,** *Guide Lamp Division, Anderson, Indiana, for a Vibration Absorbing Lamp Mounting, No. 2,686,868, issued August 17.* This device is a lamp having a socket structure which includes a rubber flange held between the lamp casing and the lens to provide shock resistance and an effective seal.

- **Albert R. Lewellen, Jr., John H. Diedring, David P. Clayton, and Robert N. Falge,** *Chevrolet Motor Division, Detroit, Michigan, and Guide Lamp Division, Anderson, Indiana, respectively, for a Headlight Gasket Fastening Device, No. 2,686,867, issued August 17.* This patent concerns a wire fastening device for use in automotive headlamps having means to secure juxtaposed ends of a split annular gasket to allow use of an inexpensive extruded gasket.



Mr. Diedring serves as general supervisor of drafting in the Engineering Department of Guide Lamp. Employed as a draftsman in 1928 by the Guide Motor Lamp Company (later a Division of General Motors), he was promoted through the positions of designer, checker, assistant chief draftsman, and chief draftsman to his present position. Mr. Diedring attended Fenn College, Cleveland, Ohio, and is a member of the Ordnance Lamp Subcommittee of the S.A.E. Lighting Committee and of the GM Standards Committee. This is the fifth patent granted for his work with automotive lighting.

Mr. Lewellen is a design engineer in Chevrolet's Engineering Department. Mr. Lewellen joined Chevrolet over 27 years ago when he was originally hired as a tracer in 1927. From 1928 until 1933 he worked as a detailer and in 1935 he was promoted to layout work. After regular promotions in this work he was made design supervisor in 1946. Two years later he advanced to senior project engineer and in 1952 attained his present position. Mr. Lewellen, at present, is concerned primarily with the design of chassis electrical equipment.

Mr. Clayton serves as junior designer in the Engineering Department of Guide Lamp. Since joining the Division in 1939 as a paint rack repairman, he also has served as model shop crib attendant, apprentice model maker, model maker, and draftsman. He became a junior designer in December 1951.

Mr. Falge has served since 1937 as chief engineer at Guide Lamp. He was originally employed by GM in 1927 by the Research Laboratories Division, Detroit. He received a degree in electrical engineering from University of Wisc sin in 1916. He serves on import committees on vehicle lighting in S.A.E., Automobile Manufacturers sociation, and the National Commit on Uniform Traffic Laws and Ordinanc

- **Roger H. Harrison and Virgin Reddy,** *Detroit Diesel Engine Divisi Detroit, Michigan, for a Dual Fuel Engi No. 2,686,503, issued August 17.* T patent covers an internal combusti engine operable either on gas fuel w pilot oil fuel injected for ignition pu poses, or on oil fuel injection alone wi an improved governor control of the tw fuel deliveries.

Mr. Harrison is a project engineer the Engineering Department at Detro Diesel Engine. He began his emplo ment in that Department in 1948 as senior detailer and, in 1951, he was pr moted to layout draftsman. Three yea later he became a designer and September of the same year he was pr moted to his present position in whi he is currently engaged in the develo ment of engine governors. He was pr viously concerned with the design of dual-fuel engine. Mr. Harrison receiv the B.S.M.E. degree from Univers of Michigan in 1948 and is a member the Awards Committee of the Enginee ing Society of Detroit.

Mr. Reddy serves as a developme engineer in the Engineering Departme at Detroit Diesel Engine where he is charge of all basic engine development work. Mr. Reddy joined this Divisio in 1938 as supervisor of the Engineerin Laboratory. He received the M.S. degr in mechanical engineering from Iow State College in 1935 and completed graduate course in Diesel engineering General Motors Institute in 1936. H work has resulted in several patents the field of governors and dual-fu engines.

- **Thomas O. Mathues,** *Inland Manufa turing Division, Dayton, Ohio, for an Inert Switch, No. 2,686,853, issued August 1* This invention is directed to an inert switch which includes a pendulum th is the switch actuating member, whi pendulum is dampened in its mov ments so that it is only responsive rapid changes in acceleration. In th manner, the switch may be used operate signal lights when a vehicle brought to an emergency stop.

Mr. Mathues has served as director of boratories at Inland since 1952. He ined the Division in 1940 as an engi-ering student and was promoted to nior estimator in 1944, to junior test gineer in 1946, to project engineer—tex products in 1948, to supervisor of e Physical Test Laboratory in 1950, d to his present position in 1952. Mr. lathues was granted the B.M.E. degree om General Motors Institute in 1947. is technical affiliations include chair-anship of the Dayton Section of the A.E. and membership in the American ociety for Testing Materials. His com-ittee work includes work on the S.A.E. ommittee for the Laboratory Evalua-on of Brake Linings.

Charles L. McCuen, *Research Labora-ries Division, Detroit, Michigan, for a ariable Compression Ratio Engine, No. 686,505, issued August 17.* This invention lates to a novel lever, link, pump, and alve means for operating movable walls mployed in a variable compression atio engine.

Mr. McCuen is vice president of eneral Motors and general manager f the Research Laboratories Division, post he has occupied since 1947. Ir. McCuen previously served as vice resident in charge of engineering from 940 to 1947. He joined GM in 1926 s a member of the engineering staff of ldsmobile Division. He later became hief engineer at Oldsmobile and in 1933 e was appointed general manager of hat Division. He is credited with the evelopment of the series F and series L, - and 8-cylinder Oldsmobile engines nd numerous patents have resulted rom his work in the fields of engine omponents and spring suspensions. He vas graduated from the Polytechnic ollege of Engineering, Oakland, Cali-ornia, in 1911 and was awarded an onorary degree by the same institution n 1934.

Joseph R. Pichler, *ayton, Ohio, for a Display Refrigerating pparatus, No. 2,686,405, issued August 17.* he invention of this patent discloses a elf-locating air deflecting cap on the pper end of a hollow air circulating lue of an open-top refrigerated food isplay case to deflect cold air laterally nto the case.

Mr. Pichler is section head of the ommercial Engineering Department of

Frigidaire. He joined this Division in 1934 as a tracer after receiving the Bachelor of Industrial Engineering degree from Ohio State University. After a series of promotions, which included project engineer on war products, he assumed his present position in 1950. His work in the field of refrigeration has included developmental work on refrigerated display cases and, at the present time, he is concerned with automatic ice-cube makers and with reach-in refrigerators.

• **John O. Almen**, *Research Laboratories Division, Detroit, Michigan, for Gearing, No. 2,687,653, issued August 31.* This invention deals with a lightweight bevel gear set where the tooth load acts substantially parallel to the gear wheel web and in a manner to balance the normal displacement of the tooth load to permit the lightweight gear to carry a high load.

Mr. Almen retired in 1952 after serving for 26 years in the Research Laboratories as an engineer and consultant. He joined this Division in 1926 as a research engineer in the Power Plant Section and in 1938 he became head of the Mechanical Engineering Department No. 1. During his career, Mr. Almen initiated developmental work on resonance silencing, contributed to a new method of designing gears from the standpoint of fatigue life, did pioneering work in shot peening, and did developmental work on extreme-pressure lubricants. Mr. Almen is an engineering graduate of Washington State College.

• **Gregory Flynn, Jr.**, *Research Laboratories Division, Detroit, Michigan, for a Connecting Rod and Piston Assembly, No. 2,687,931, issued August 31.* This patent covers a floating-type piston for two-cycle engines in which a removable wrist pin carrier is employed having means for detachably securing the connecting rod without the use of bolts.

Mr. Flynn is assistant head of the Research Laboratories' Mechanical Development Department. While a student at General Motors Institute, he served with the Chevrolet Motor Division in Flint and the Research Laboratories. Upon graduation from G.M.I. in 1941, he became a junior engineer at the Research Laboratories where he advanced through the positions of research and senior engineer to his present title in 1953. His experience included a two-year term of duty with the U. S. Navy. Mr. Flynn's primary field of development is in free-piston, Diesel, and natural-gas engine design. He is a member of the Diesel Engine Activities Committee of the S.A.E. and the U. S. Naval Institute.

• **Oliver K. Kelley**, *General Motors Engineering Staff, GM Technical Center, Detroit, Michigan, for a Rotary Hydraulic Torque Converter, No. 2,687,616, issued August 31.* This patent concerns a hydraulic torque converter in which the impeller and reaction wheel are each divided into two independently rotatable parts of particular blade design to produce an effect similar to changing blade angles during operation, which increases efficiency and gives improved operating characteristics.

Mr. Kelley is engineer-in-charge of the Transmission Development Group of the General Motors Engineering Staff, located at the GM Technical Center. He earned the B.S. degree from Chicago Technical College in 1925 and studied automotive engineering at Massachusetts Institute of Technology during 1926-27. He started with GM as a detailer at the Cadillac Motor Car Division in 1927. This patent was applied for when he was connected with Detroit Transmission Division as assistant chief engineer. He is chairman of the Captured Enemy Equipment—Transmissions Committee and the Hydrodynamic Drive Nomenclature Committee of the S.A.E.

• **Dr. Charles F. Kettering and Frank J. Roelandt**, *Research Laboratories Division, Detroit, Michigan, and General Motors Technical Center, respectively, for a Humidistat, No. 2,688,056, issued August 31.* This invention relates to a rugged humidity sensitive switch used to control apparatus to maintain a desired humidity.

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

Dr. Kettering, former vice president of General Motors and former general manager of its Research Laboratories, is now a director and research consultant. A 1904 graduate of Ohio State University with degrees in mechanical and electrical engineering, Dr. Kettering has been the recipient of numerous awards and honorary degrees throughout the world for his contributions to scientific research. Among the most important of his developments to the automotive industry have been the electrical starting, lighting, and ignition system he originated in 1910 and the discovery of anti-knock fuels. Under his guiding hand, the General Motors Research Laboratories has made many contributions to scientific research—notably, refrigerants, quick-drying lacquer finishes, tetraethyl lead, balancing machines, and the two-cycle Diesel engine.

Mr. Roelandt is a senior design engineer in the Special Problems Department of the Research Laboratories, located at the General Motors Technical Center. He was initially employed by this Department in 1948 as a detailer. Mr. Roelandt was granted the B.S. degree from Wayne University, Detroit, in 1949 and served in the U. S. Navy from 1942 to 1946, separating with the rank of motor machinist. This is the first patent granted as a result of his work with balancing machines. Previously, he worked on the mechanical heart pump.

- **Clare B. Rowland and Owen A. Christensen,** *AC Spark Plug Division, Flint, Michigan, for a Bellows Folding Machine, No. 2,687,678, issued August 31.* This patent relates to a bellows folding machine having a plurality of series of hinged plates mounted to move from a prismatic tubular form to a bellows form to fold a tube internally supported by air under pressure into a bellows.

Mr. Rowland is supervisor of the tool room, Manufacturing Development Department at AC. From 1919 until 1937 Mr. Rowland was a model maker in the Experimental Model Department at Buick Motor Division. He then transferred to AC where he was promoted to his present position in 1943. While at Buick, Mr. Rowland worked on the development of valve lifters and camshafts. Among his projects at AC have been the manufacturing development of oil filters and spark plugs while, at present, his work deals primarily with the development of rubber molded sparkplug insulators.

Mr. Christensen serves as development specialist in the Manufacturing Development Department at AC. His General Motors employment dates from 1916 when he was a motor builder in the Experimental Department of Buick Motor Division. In 1924 he transferred to AC Spark Plug Division as a foreman and regular promotions have led to his present position. In addition to the development covered by this patent, he has worked on the development of precision spindles for AC speedometers. Mr. Christensen also developed a device for making bellows from brass tubing. He is now engaged in developing an automatic machine for assembling fuel pumps, rocker arm pins, and washers. Mr. Christensen is a graduate of the Technical School of Copenhagen, Denmark.

- **Walter E. Sargeant,** *Research Laboratories Division, Detroit, Michigan, for a Combined Spark Impulse Indicator, No. 2,688,127, issued August 31.* This patent concerns indicating apparatus providing for indication of the spark impulse for each cylinder of an internal combustion engine on a different sweep trace on the face of an oscilloscope, the sweep traces being developed mechanically by rotatable cams.

Mr. Sargeant is a special problems and consultation engineer in the Physics and Instrumentation Department of the Research Laboratories. Currently, he is engaged in an investigation of the possible uses of transistors. His work at the Research Laboratories has resulted in six granted patents. Mr. Sargeant received the B.S. degree in electrical engineering from University of Michigan in 1926. He is a member of the Detroit Mathematics Society and the American Physical Society and is an associate member of Sigma Xi.

- **Edward F. Weller, Jr.,** *Research Laboratories Division, Detroit, Michigan, for a Combined Spark Impulse Indicator, No. 2,688,126, issued August 31.* This patent concerns indicating apparatus providing for indication of the spark impulse for each cylinder of an internal combustion engine on a different sweep trace on th face of an oscilloscope, the sweep trace being developed by electronic means.

Mr. Weller has served as assistan head of the Physics and Instrumentatio Department of the Research Laboratories since December 1952. He wa originally employed as a junior researc engineer in this same Department i September 1946. Mr. Weller holds th electrical engineering degree from University of Cincinnati where he wa elected to Eta Kappa Nu. This is th second patent resulting from his work He has authored a paper dealing with new mixture ratio analyzer.

- **William E. Brill,** *Cleveland Diesel Engin Division, Cleveland, Ohio, for Crankcas Ventilation, No. 2,688,316, issued Septembe* 7. This is a patent on an arrangement of suction pump and oil separator fo ventilating an engine crankcase in which all of the oil separated is assured return to the crankcase.

Mr. Brill has been an engineer a Cleveland Diesel Engine since Apri 1933. He earned his engineering degre in 1925 from Case Institute of Technology and has spent most of his caree on Diesel engines, in which field his work has resulted in several granted patent He is engaged, at present, on long-rang projects as a development engineer. Mr Brill has been active in the Society Automotive Engineers and in the American Society of Mechanical Engineers

- **Leland D. Cobb,** *New Departure Division, Bristol, Connecticut, for a Demountabl Seal, No. 2,688,502, issued September 7.* Thi patent is for a demountable end sealing closure in an antifriction bearing which retains lubricant within the bearing an excludes dirt from the bearing.

Mr. Cobb serves as manager of th Research and Development Laborator at New Departure. He started with th Division in 1928 as a junior engineer an was promoted through the positions o physical test engineer, project enginee on textile applications, executive engineer, assistant to the general manage and manager of Research and Development to his present position, manager o the Research and Development Laboratory. Mr. Cobb attended Pratt Institut in New York. He is a member of th American Society of Mechanical Engineers, the Society of Automotive Engineers, and serves on a committee of th American Standards Association.

These patent descriptions are ininformative only and are not intended to define the coverage which is determined by the claims of each one.

- **Howard M. Geyer,** *Aeroproducts Operations of Allison Division, Dayton, Ohio, for a Dual Drive Actuator, No. 2,688,227, issued September 7.* This patent relates to a dual-drive actuator having a cylinder and a piston, wherein the piston may be reciprocated either by fluid pressure or by a reversible electric motor, in combination with locking means which can only be released to permit movement of the piston in one direction at any one time.

- **Howard M. Geyer,** *Aeroproducts Operations of Allison Division, Dayton, Ohio, for a Synchronized Locking Actuator, No. 2,688,232, issued September 7.* This patent relates to a fluid pressure operated actuator designed for the synchronous operation with other like actuators including means for locking each actuator in any adjusted position.

Mr. Geyer serves as chief product research engineer at Aeroproducts Operations of Allison. He earned the B.S. degree in industrial engineering from University of Alabama in 1940. He joined Aeroproducts in August 1940 as a junior draftsman and advanced through the positions of designer, senior designer, and senior project engineer until promoted to his present status. At present, he is concerned with dual-drive servo control mechanisms.

- **Arthur J. Anderson,** *Fabricast Division, Bedford, Indiana, for a Machine and Process for Forming Hollow Sand Resin Cores, No. 2,688,780, issued September 14.* This patent pertains to an apparatus for forming hollow, shell-type foundry cores by means of spatially separated metallic core box members, one of which is heated and one unheated.

Mr. Anderson serves as a process engineer in the Process Engineering Department at Fabricast. His initial General Motors employment was in 1935 with Delco-Remy Division as a plater helper. From 1940 to 1945 he was employed by the Allison Division as a foundry contact representative. He then transferred to Fabricast, advancing through the positions of foreman, junior process engineer, engineer—research and experimental, to his present position. This patent was granted as a result of his work with shell molded cores. A previous patent was granted based on his work on a core lifting and setting fixture.

- **James S. Burge, Floyd J. Foust, Willard C. Shaw, Hilton J. McKee, and Warren M. Rider,** *Delco-Remy Division,*

Anderson, Indiana, for an Ejecting and Counting Mechanism, No. 2,689,086, issued September 14. This patent deals with an assembly machine and is specifically directed to an ejecting and counting mechanism whereby parts assembled by the machine are counted and then ejected therefrom.

Mr. Burge is no longer with the Division.

Mr. Foust is inspection supervisor of machine tool or die design at Delco-Remy. He attended Purdue University. Delco-Remy employed Mr. Foust in 1939 as an inspector. Subsequently, he was promoted to foreman in 1943, to junior engineer in 1945, and to his present position in 1950. His present work is concerned with electronic equipment.

Mr. Shaw is employed at Delco-Remy as engineer—project on design. He began at this Division in 1939 as a tool making apprentice. In 1943 he was promoted to tool maker and in 1945 he became senior designer. He was made foreman of the tool room in 1950, serving until attaining his present position in 1952. He attended Ball State Teachers College.

Mr. McKee serves as an engineer in the Process Department of Delco-Remy where he was originally employed in 1942. In 1943 he was promoted to junior engineer and, two years later, to senior designer. He is a 1932 graduate of Ball State Teachers College, Muncie, Indiana, and has spent most of his career on the design of electrical machinery.

Mr. Rider is no longer with the Division.

- **Milton J. Diamond,** *Central Foundry Division, Saginaw, Michigan, for a Magnetic Hardness Tester, No. 2,689,042, issued September 14.* This invention relates to a system for magnetically testing the hardness of metal parts, which system has one pickup and a plurality of amplifier paths therefrom to switching means for adjusting the upper and lower selection limits independently.

Mr. Diamond is research engineer at Central Foundry. He earned the B.S.E.E. degree from University of Detroit in 1932. He was originally employed by GM in 1936 as an electrician and was promoted to engineer in the Defiance, Ohio, plant project in 1947 and to research engineer in 1950. Mr. Diamond's previous projects include work in shell molding and electronic hardness testing. To date, Mr. Diamond's research in these fields has resulted in three granted patents.

- **C. W. Lincoln,** *Saginaw Steering Gear Division, Saginaw, Michigan, for a Ball Nut and Lever Steering Gear, No. 2,688,885, issued September 14.* This apparatus relates to steering gears of the ball-nut and lever-type with substantially no lost motion between the nut and Pitman shaft when the gear is on center and having means for damping the movement of the operating parts as they approach center.

Mr. Lincoln is chief engineer at Saginaw Steering Gear. He was originally employed by General Motors in 1932 as a tool and machine designer at this Division. Mr. Lincoln received the B.S. degree in 1915 from University of Illinois. He is a member of Tau Beta Pi and the Governing Board of Mid-Michigan Section of the Society of Automotive Engineers.

- **George R. Long,** *Frigidaire Division, Dayton, Ohio, for an Apparatus for Drying Fabrics, No. 2,688,806, issued September 14.* This patent relates to a water spray system for a clothes dryer that is maintained effective by a heat exchanger cooled by circulating air thereover to maintain water in the spray system at a temperature below that of the heated moist air leaving the fabrics.

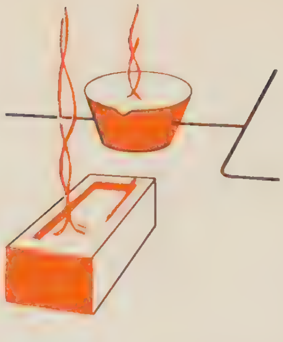
Mr. Long is manager of Frigidaire's Materials and Process Engineering Department—a post he has held since 1937. He directs developmental work in metallurgy, porcelain enamel, paints, refrigerants, oils, and plastics. His 27-year association with Frigidaire began as a co-op student from Antioch College. Later, he was advanced to the positions of metallurgist and section head-in-charge of materials and processes at two Frigidaire plants. He holds the B.S. degree in chemistry from Antioch College (1927) and the B.S. degree in metallurgy from Massachusetts Institute of Technology (1929). He is a member of several technical societies and is a past chairman of the Dayton Section, A.S.M.

- **Charles J. O'Brien**, *Harrison Radiator Division, Lockport, New York, for a Heat Exchanger, No. 2,688,986, issued September 14.* This patent concerns an improved heat exchanger for fluids such as oil and comprises a tube through which a treated fluid is to pass and a deflecting strip extending the length of the tube with flanges and slits on the strip to increase fluid turbulence.

Mr. O'Brien serves as senior engineer—research and experimental in the Engineering Department of Harrison Radiator. After receiving the B.S.M.E. degree from Clarkson College of Technology in 1927, Mr. O'Brien was employed by Harrison Radiator as an engineer. His major promotions since then include: technical data supervisor in 1930, junior engineer in 1934, development engineer in 1936, research engineer in 1940, assistant section engineer in 1942, and his present position in 1948. Mr. O'Brien has done previous developmental work on heat exchangers, aviation oil cooler valves, locomotive oil coolers, and aluminum radiators—in addition to his present work on thermostats.

- **Elmer Olson**, *Rochester Products Division, Rochester, New York, for a Carburetor, No. 2,689,115, issued September 14.* This patent covers an arrangement for supplying idling fuel in a carburetor and the novelty resides in the specific arrangement of fuel supply passages which are variably controlled by the throttle as it progressively moves from the normal idle position toward open position, and the purpose of the device is to prevent overrichness of the idling mixture as the throttle is so moved.

Mr. Olson has been chief engineer of Rochester Products since his employment in 1945. He attended the Lewis Institute in Chicago. At present, he is concerned principally with studies on carburetion and fuel handling devices. Previously, he worked with carburetors and allied products such as automatic chokes, fuel pumps, and governors as combined with carburetors. He is a member of the Carburetor Flanges Committee and the Standardization Committee of the Society of Automotive Engineers.



- **George H. Strickland**, *Patent Section, Dayton, Ohio, for a Household Refrigerator with Humidity Control, No. 2,689,110, issued September 14.* This invention concerns a refrigerator having means for removing excess humidity from a food storage compartment without materially changing the food preserving temperature of the storage compartment.

Mr. Strickland is assistant director of the Patent Section, in charge of the Section's office located at Dayton, Ohio. He joined General Motors in 1929 as a patent attorney, was promoted to attorney-in-charge of the Dayton Office in 1951, and was named assistant director of the Patent Section in 1952. Mr. Strickland attended Harvard College and George Washington Law School and is a member of the bar of the District of Columbia and the State of Ohio.

- **Calvin J. Werner**, *Delco Products Division, Dayton, Ohio, for a Locking Washer, No. 2,689,146, issued September 14.* This invention concerns a locking washer non-rotatively securing a member on a smooth shaft.

Mr. Werner is plants manager of Delco Products. During his 31-year association with the Division his work has led to a total of 57 granted patents in the fields of electric motors and control devices and hydraulic shock absorbers. Mr. Werner was granted the electrical engineering degree from University of Cincinnati in 1930. His professional affiliations include membership in the S.A.E., Eta Kappa Nu, and Tau Beta Pi. In addition, he is a Fellow of the American Institute of Electrical Engineers and is president of the Engineers Club of Dayton.

- **Richard Arf**, *Frigidaire Division, Dayton, Ohio, for a Charging Refrigerating Apparatus, No. 2,689,463, issued September 21.* The device of this patent is a small charging device for volatile refrigerants intended for use in repair shops for recharging damaged automobile air conditioning systems.

Mr. Arf is a sales engineer in the Direct Factory Sales Department at Frigidaire. He began his career with General Motors in 1942 as a production engineer at Fisher Body Division. He transferred to General Motors Overseas Division before beginning development work on automobile air conditioning for Frigidaire. Mr. Arf earned the B.S. degree from Massachusetts Institute of Technology in 1928. Seven patents have resulted from Mr. Arf's work in air conditioning and refrigeration.

- **Anton M. Schaffer**, *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus, No. 2,689,622, issued September 21.* This patent concerns a sealed motor compressor unit in which the refrigerant outlet is provided with a centrifugal oil separator in the form of a squirrel cage rotor with trailing blades driven by an extension of the motor compressor shaft.

Mr. Schaffer is a layout draftsman at Frigidaire where his present work is concerned with compressor design. Before coming to General Motors, Mr. Schaffer was associated with the Department of Conservation and Development in New Jersey. In 1942 he was employed by Eastern Aircraft Division, Linden, New Jersey, and in 1945 he transferred to Frigidaire. Previous assignments involved drafting window units for air conditioning. This is the first patent issued from Mr. Schaffer's work in refrigeration.

- **John E. Storer, Jr. and William G. Livezey**, *Allison Division, Indianapolis, Indiana, for a Steering Drive for Vehicle Transmission, No. 2,689,488, issued September 21.* This patent concerns improved apparatus for driving the steering clutches of a transmission for a track-type vehicle to give maximum steering ability under all conditions of vehicle operation.

- **John E. Storer, Jr., William G. Livezey, and Elmer A. Richards**, *Allison Division, Indianapolis, Indiana, for a Steering Control System for Vehicles, No. 2,689,489, issued September 21.* This patent disclosed apparatus responsive to the difference in the speed of the tracks of a track-type vehicle for automatically regulating the steering clutches to maintain a constant rate of turning which may be manually determined.

Mr. Storer has been chief engineer in the Transmission Engineering Department at Allison since 1951. He was originally employed by Buick Motor

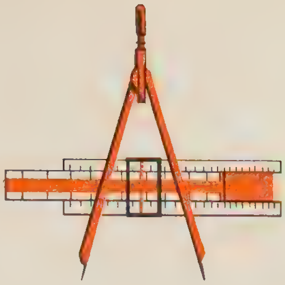
Division, Flint, Michigan, in 1929 as a General Motors Institute student, graduating from the Institute in 1932. He transferred to Allison Division in 1940, was promoted to engineer-in-charge of the Propeller Drive Group in 1942, and was promoted to chief ordnance engineer in 1946. He has authored several papers on military torque converter transmissions.

Mr. Livezey is chief designer in the Transmission Engineering Department of Allison. He joined Allison in 1936 as an experimental assembler. He was promoted through test engineer (1941), senior test engineer (1943), and senior project engineer (1948). He was appointed to his present position in 1952. Mr. Livezey is a 1937 mechanical engineering graduate of the International School of Correspondence. Mr. Livezey's present duties include future transmission design studies.

Mr. Richards is supervisor of the Manufacturing Methods Development Department of the Transmission Operations, Allison Division. His GM career started as a cooperative student at General Motors Institute where he enrolled in 1933. After graduation in 1937, he joined the Technical Data Department of the Research Laboratories Division where he remained until 1940 when he transferred to Allison as head of the Technical Data Department. Three years later he became supervisor of the Components Test Laboratory and, in 1945, became project engineer on a post-war hydraulic transmission. Subsequently, he served as chief test engineer and ordnance transmission engineer before assuming his present position.

• **Louis J. VanSlooten,** *Diesel Equipment Division, Grand Rapids, Michigan, for a Hydraulic Valve Lifter, No. 2,689,555, issued September 21.* This relates to a self-adjusting tappet of the self-contained hydraulic-type, employing a bellows element to seal the reciprocating parts against loss of fluid.

Mr. VanSlooten is a customer contact man in the Engineering Department at Diesel Equipment. His General Motors employment began with that Division in 1948 as a senior detailer. In 1950 he was promoted to layout man and since 1953 he has been engaged in development work on hydraulic valve lifters. Mr. VanSlooten, a Purple Heart veteran, served in the Army from 1941 to 1945, both at Pearl Harbor and in the European Theater.



• **Clifford H. Wurtz,** *Frigidaire Division, Dayton, Ohio, for a Refrigerating Apparatus Mounting Means, No. 2,689,464, issued September 21.* This invention relates to a vibration insulating mounting bracket made of resin impregnated fibers for securing a compressor to a stationary support and eliminating the need for hold-down bolts during shipment.

Mr. Wurtz is supervisor of the major product line at Frigidaire. Directly after earning the B.S. degree from University of Illinois in 1929, he joined this Division. After completing an engineer-in-training program he was made a junior tester and, in early 1938, was promoted to senior tester. Later in the same year, he advanced to junior engineer and in 1942 was promoted to senior engineer. In 1950 he was appointed section engineer and, two years later, was promoted to his present position. His work has included the development of a cycla-matic system of automatic defrosting.

• **Raymond C. Davis,** *Inland Manufacturing Division, Dayton, Ohio, for a Rotary Fan Impeller, No. 2,690,063, issued September 28.* This patent relates to a means for mounting the blades of a fan on the rotating shaft of the operating motor. The motor shaft has a hub with an outwardly projecting flange while the fan blades are secured to an annular member having an inwardly projecting flange. These flanges are received in opposed grooves formed in an annular connecting member of resilient material such as rubber.

Mr. Davis is assistant to the chief engineer at Inland. He received his mechanical engineering degree from Dayton Night College in 1920. He was employed by Inland in April 1931 as an engineering designer and became chief draftsman in 1936 and assistant to the chief engineer in 1942. Before joining Inland, he was employed by Frigidaire Division and by its predecessor, Delco Light Company.

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

• **Harold V. Elliott and Argyle G. Lautzenhiser,** *Delco-Remy Division, Anderson, Indiana, for a Direction Signal Switch Mechanism, No. 2,690,483, issued September 28.* This invention deals with a direction signal control wherein the operating mechanism is disposed at the lower extremity of the steering column and is adapted for actuation by a manual control located adjacent the steering wheel.

Mr. Elliott is project engineer at Delco-Remy. He began in 1936 as a blueprint operator in Delco-Remy's Engineering Department and, shortly afterward, transferred to the model shop. During this period, he was enrolled as a cooperative engineering student at General Motors Institute from which he was graduated in 1938. In 1941 he became a laboratory technician and a year later entered the U. S. Navy. He was with the Research Laboratory at Delco-Remy from 1948 to 1950 and was appointed to his present position in 1951.

Mr. Lautzenhiser is research engineer at the Delco-Remy Division. He earned the B.S. degree in electrical engineering from Tri-State College, Angola, Indiana, in 1940. After his employment by Delco-Remy in 1940 as a laboratory technician, he was promoted to special tester in 1942 and to research engineer in 1948. He served in the Army from 1944 until 1946.

• **Richard L. Jenkins,** *Delco Radio Division, Kokomo, Indiana, for a Signal Actuated Tuner Control, No. 2,690,506, issued September 28.* This invention relates to a signal-seeking control circuit for switching different impedances into the trigger tube control circuit for different operating phases so that the tube will not burn out.

Mr. Jenkins, senior engineer in Delco Radio's Engineering Department, was originally employed in 1944 as a student engineer. Regular promotions led to his present senior engineer level of responsibility. Mr. Jenkins assisted in the development of various military countermeasure and communications equipment during World War II and, more recently, contributed to the development of Delco Radio's first signal-seeking radios. At present, he is assigned to give engineering assistance to the production of T-38 electronic assemblies. He earned the B.S.E.E. degree from Purdue University in 1944 and is a member of the I.R.E. and the honorary societies Tau Beta Pi and Eta Kappa Nu.

- **Thomas L. Kendall**, *Delco-Remy Division, Muncie, Indiana, for a Vent Plug, No. 2,690,467, issued September 28.* This invention relates to a submersible vent cap for a storage battery having removable valving means for conversion of the cap into a conventional unvalved-type cap when desired.

Mr. Kendall serves as chief engineer for battery operations. He earned the B.S. degree in chemical engineering from Purdue University in 1933. In 1934 he was employed by Delco-Remy as a repairman. He served in the Army from 1941 to 1946, attaining the rank of lieutenant colonel. He is a member of the Society of Automotive Engineers, the Electrochemical Society, and the American Chemical Society.

- **Charles J. McDowall**, *Allison Division, Indianapolis, Indiana, for a Clutch Plate with Grooves for Lubricant or Coolant, No. 2,690,248, issued September 28.* This invention consists of a clutch and a plate with the plate having radial channels for circulation of a cooling and lubricating fluid, the channels being connected by generally circumferential grooves.

Mr. McDowall serves as chief—turbine components in the Aircraft Engineering Department of Allison. In 1927 he was granted the B.S.M.E. degree from University of Florida. His General Motors career began in 1932 when he was initially employed by Allison as a junior engineer. He is presently engaged in the development of controls and combustion for the T-40, T-56, and J-71 engines. Mr. McDowall is a member of the Aircraft Engineering Division of the S.A.E. and has previously served on several committees of the S.A.E. and the National Advisory Committee for Aeronautics.

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

A Typical Problem in Automotive Design:

Determine the Shape of a Cantilever Spring of Minimum Stress for Door-Check and Hold-Open Application

The main component of an automotive door-check and hold-open mechanism is a cantilever spring which must be of sufficient strength and durability to withstand the high stress conditions to which it is subjected. If a spring material of high tensile strength were used, the required strength and durability characteristics would be met but the cost of production would be high. In searching for a material which provides both quality and production economy, engineers learned that ordinary spring-steel material is excellent, but its use necessitates a design which will reduce the stress on the spring to a minimum. The problem is to design the spring by varying its width so that the stress will be the minimum obtainable under the design conditions given. The solution to the problem will appear in the March-April 1955 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

THE door-check and hold-open mechanism represents but one of the many products which fall under the general classification of automobile hardware. This mechanism has as its main component a cantilever spring which is placed under conditions of high stress while performing its intended function.

The design specifications for the door-check and hold-open mechanism require that the spring be small enough to fit in the configuration given and also be of sufficient strength and durability to withstand the loads applied for the life cycle desired.

The difficulty usually encountered in

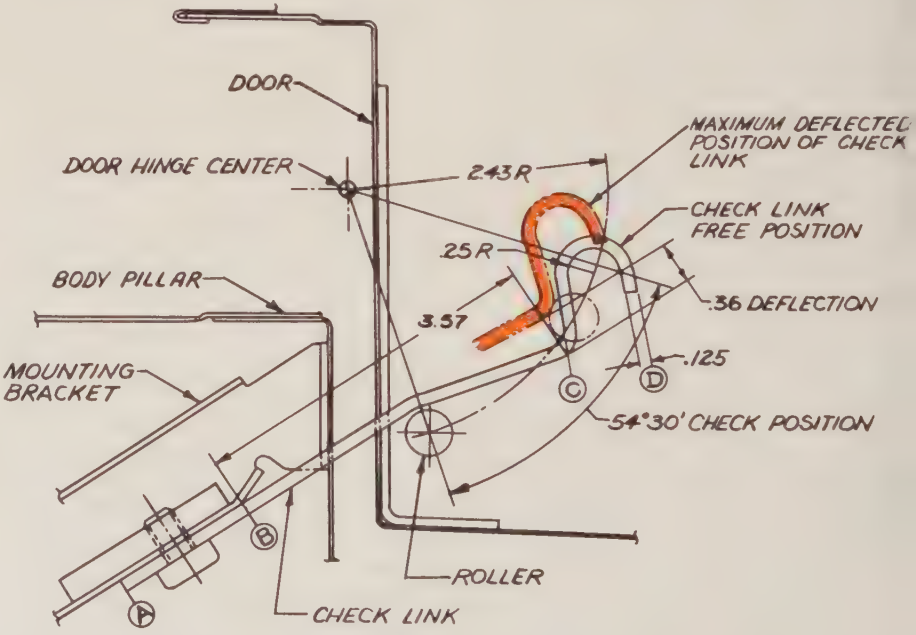


Fig. 1—The door-check and hold-open mechanism has as its main component a cantilever spring which is called the *check link*. When the door is closed the cantilever spring, rigidly attached between points **A** and **B** to the body pillar by means of a mounting bracket and a bolt, is in contact with a roller mounted on the inside edge of the door. As the door is swung open, the roller follows a horizontal path of travel and causes the spring to be deflected between points **B** and **C**. As the roller approaches the end of its 54° 30′ path of travel, the cantilever spring is deflected its maximum amount of 0.36 in., indicated in color. The hook-end section of the spring, between points **C** and **D** then snaps onto the roller, thereby preventing further outward movement of the door.

By **BARTHOLD F. MEYER**
Ternstedt
Division

Find a spring shape to lower tensile stress, save material

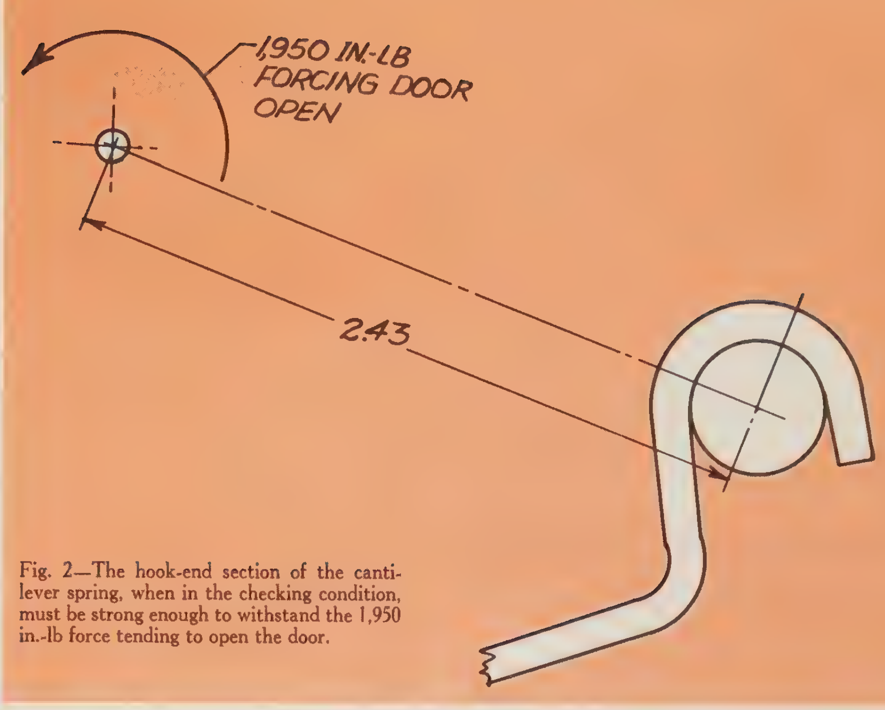


Fig. 2—The hook-end section of the cantilever spring, when in the checking condition, must be strong enough to withstand the 1,950 in.-lb force tending to open the door.

meeting the design specifications for the cantilever spring is one of reducing the ratio of the operating stress to the yield stress. This can be accomplished by increasing the inherent strength of the spring material, varying the thickness of the spring material along its length, or by varying the width of the spring.

The simplest way to meet the design specifications is to use a spring material of greater tensile strength. This, however, is not the most economical method. While the cost of using a high tensile strength spring-steel material over one of lower tensile strength might amount to only a few cents per spring, the production volume for the spring is such that the overall cost would be quite high.

The most economical method of designing the cantilever spring is to use an ordinary flat, bar-stock, spring-steel material of rectangular cross section and rectangular shape such as S.A.E. 1060. In a majority of cases, a cantilever spring so designed performs its function in door-check and hold-open applications in an entirely satisfactory manner. There are instances, however, where a spring of this shape will be overstressed so that additional engineering is required in order that the spring be able to fulfill the stress and size specifications.

Fig. 1 shows a plan view of a door-check and hold-open mechanism and its relationship to the door, door hinge, and body pillar. The cantilever spring, which is called the *check link*, is attached to the body pillar by means of a sheet-metal mounting bracket and a bolt. The spring, in turn, is in contact with a roller which is assembled to the inside edge of the door. As the door is swung open, the roller begins a horizontal path of travel and in so doing causes the spring to be deflected. When the roller reaches the end of its travel, the spring is at its maximum deflected position of 0.36 in. When this position is reached, the hook-end section of the spring then snaps onto the roller and further outward movement of the door is prevented. The spring is then said to be in the checking condition (Fig. 2). As the door is closed the roller comes in contact with the camming surface of the spring. This surface is so designed that the major portion of the force exerted by the roller is taken on the spring in column. The remainder of the force causes lateral bending of the spring.

Problem

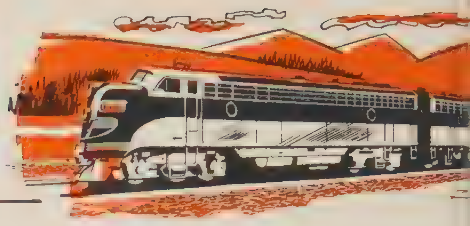
Assume that the spring is too highly stressed to suit the conditions shown in Fig. 1. It is desired to use a flat, bar-stock, spring-steel material and reduce the stress on the spring to a minimum value. This is to be accomplished by designing the spring to be of varying width. The spring, however, must still be able to operate with the maximum required deflection of 0.36 in.

Information which is pertinent to the solution of the problem is as follows. The maximum allowable stress for the spring is 145,000 psi. The spring is to be made from flat, bar-stock, spring steel of 0.125 in. thickness which must be maintained. Space considerations are such that the maximum allowable width is 1.25 in. This width is to be maintained between points **A** and **B** in Fig. 1 which represents the fixed end of the cantilever spring. The length of the spring between points **B** and **C** is to be 3.57 in. which is the length of the spring between these two points at maximum deflection. The width of the hook-end section of the spring, between points **C** and **D**, while in the checking condition must be such that failure will not occur due to forces tending to open the door. The maximum force tending to open the door is 1,950 in.-lb at the door-hinge center.

A suggestion as to problem solution procedure is to determine first the force exerted by the roller on the hook-end section of the spring due to the force tending to open the door. This will then enable the calculation of the minimum allowable width of the spring's hook-end section necessary to withstand the maximum allowable stress of 145,000 psi. With this calculated width, the shape of the spring between points **B** and **C** will then be known. The last step to the solution will be to determine the stress to which this section is subjected while being deflected 0.36 in. It should be mentioned that the last step of the solution will be based on the *area-moments method* of calculating deflection.

The solution to the problem will appear in the March-April 1955 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

Solution to the Previous Problem:
Find the Wheel Loads of a Railway Truck of Novel Design



Problems are encountered in locomotive trucks which depend, to some extent, on mechanics for their solution. The mechanics may be simple or complex, but always plays an important part in calculating wheel loads. From the standpoint of safety it is important that the wheels of the truck carry loads as nearly equal as possible. A train wreck may occur due to a lightly loaded wheel jumping the track. This is the solution, as used by Electro-Motive engineers, to the problem presented in the November-December 1954 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

THE solution to the problem for determining the wheel loads could be obtained graphically if only approximate answers were desired, but for greater accuracy an analytical solution is used. Fig. 1 shows a sketch of the railway truck with the dimensions necessary for calculation.

The problem stated that the truck supports a load of 100,000 lb at point **A** through the bolster and spring supports. Points **B** and **B**′ denote the location of the spring supports and points **C** and **C**′ indicate the location of the universal joints which permit the truck structure to pivot and, therefore, afford flexibility.

The requirement of the problem was to calculate the load at each wheel, $\mathbf{W}_1$, $\mathbf{W}_2$, $\mathbf{W}_3$, and $\mathbf{W}_4$. A further requirement was proposed that, if the wheels were unequally loaded, a correction should be made that would give the desired result of equal wheel loading without changing the basic design of the truck. The solution to the problem is carried out with the aid of Fig. 2 which shows the construction lines needed to solve the problem.

The problem can best be solved by employing the use of geometry, trigonometry, and mechanics. Due to the symmetrical design of the truck, the 100,000 lb load at point **A** can be carried by the spring supports at **B** and **B**′, each point carrying 50,000 lb. Since the chief requirement is to have the wheels equally loaded, the portion of Fig. 2 marked *free body* can be used in writing a moment equation. In this manner, the forces $\mathbf{W}_1$ and $\mathbf{W}_2$ can be solved for and, if not equal, the correction to the design called for in the problem's second requirement then can be made.

In order to write a moment equation about the moment axis which passes through the universal joints **C** and **C**′, it is first necessary to calculate the lengths of three moment arms, namely aB, gW_2,

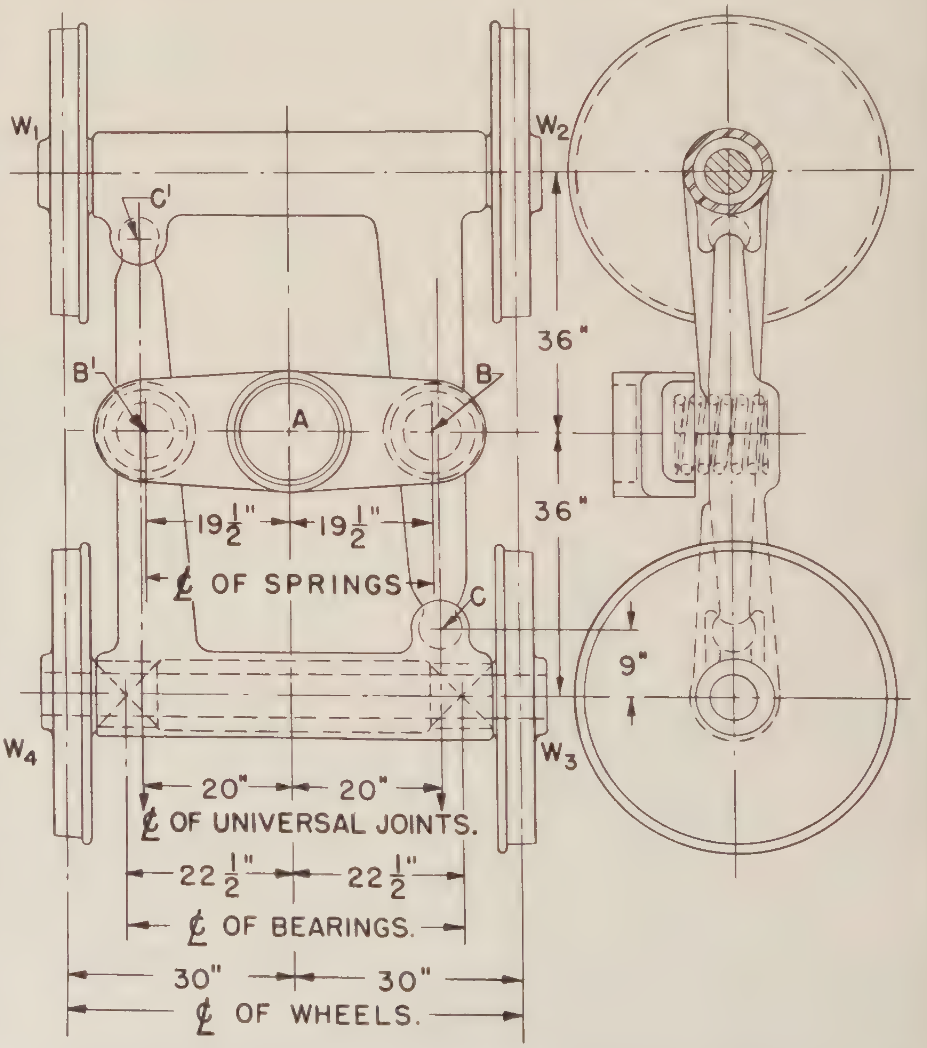


Fig. 1—Approximation sketch of a railway truck of novel design. The truck supports a load of 100,000 lb at point **A** through the bolster and spring supports located at points **B** and **B**′. The location of universal joints at **C** and **C**′ provide flexibility for the truck.

By **IVAN H. SPOOR**
Electro-Motive Division

Geometry and mechanics solve a typical problem

and fW_1. With the lengths of the moment arms known it is possible to write the moment equation and to solve for W_1 and W_2.

STEP 1—Calculate the length of moment arm aB:

In triangles ABa and ACb:
AB is similar to AC
therefore, $ab{:}AB$ as $bC{:}AC$
or: $ab = (AB)(bC)/(AC)$
$AC = \sqrt{27^2+20^2} = \sqrt{1129} = 33.60$ in.
$bC = 36$ in. $- 9$ in. $= 27$ in.
$AB = 19.5$ in.
Substituting and solving for aB:
$aB = 19.5 \times 27/33.6 = 15.68$ in.

STEP 2—Calculate the length of moment arm fW_1:

Triangle eDC' is similar to triangle AbC
therefore, $eD{:}Ab$ as $DC'{:}bC$
or: $eD = (Ab)(DC')/(bC)$
$eD = 20 \times 9 / 27 = 6.67$ in.
Triangle W_1fe is similar to triangle ABa
therefore, $fW_1{:}aB$ as $eW_1{:}AB$
$eW_1 = 30 - (20 + 6.67) = 3.33$ in.
Substituting and solving for fW_1:
$fW_1 = (aB)(eW_1)/(AB) = 15.68 \times 3.33 / 19.5 = 2.68$ in.

STEP 3—Calculate the length of moment arm gW_2;

Triangle geW_2 is similar to CAb
therefore, $gW_2{:}bC$ as $eW_2{:}AC$
or: $gW_2 = (bC)(eW_2)/(AC)$
$eW_2 = 30 + 20 + 6.67 = 56.67$ in.
Substituting and solving for gW_2:
$gW_2 = 27 \times 56.67 / 33.60 = 45.55$ in.

With the calculations completed for the required moment arms, a moment equation about the moment axis can now be written, keeping in mind that moments clockwise equal moments counterclockwise.

STEP 4—Moment balance about the moment axis:

$50{,}000 \text{ lb} \times 15.68 \text{ in.} + W_1 \times 2.68 \text{ in.} = W_2 \times 45.5 \text{ in.}$
$784{,}000 \text{ in.-lb} = 45.5\ W_2 - 2.68\ W_1.$
By vertical resolution:
$50{,}000 \text{ lb} = W_1 + W_2$
$W_2 = 50{,}000 - W_1.$

Substituting the value for W_2 into the moment equation:

$784{,}000 \text{ in.-lb.} = 45.5\ (50{,}000 - W_1) - 2.68\ W_1$
$784{,}000 \text{ in.-lb} = 2{,}275{,}000 - 45.5\ W_1 - 2.68\ W_1$
$48.18\ W_1 = 1{,}491{,}000$
$W_1 = 1{,}491{,}000 / 48.18$
$W_1 = 31{,}000$ lb
$W_2 = 50{,}000 - W_1 = 50{,}000 - 31{,}000$
$W_2 = 19{,}000$ lb.

The above calculations show that, in spite of the symmetrical design of the truck, the wheels are unequally loaded. In order to have safe conditions the wheels must carry equal loads as nearly as possible. This is due to the fact that a train can be wrecked by a lightly loaded wheel which may jump the track. It is apparent, then, that a change must be made and that this change, in keeping with the problem's second requirement, must be such that the basic design of the truck will be retained.

Examination of the truck design shows that the position of the load at point **B** is critical, and that the position of point **B** can be changed and still keep the truck's basic design. The objective of the design is to make loads W_1 and W_2 each equal to 25,000 lb. It is possible, then, that if point **B** is moved outward from the center of the truck the load requirement of each wheel can then be met. The problem is to determine how far point **B** will have to be moved.

In Fig. 2 the point **X** is the location of the new position for point **B**. The moment arm jX replaced aB in the original calculations. It is now necessary to write a new moment equation about the moment axis and solve for the distance jX. Then, by following the method used above, the distance that the point **B** must be moved from the center of the truck A may be determined.

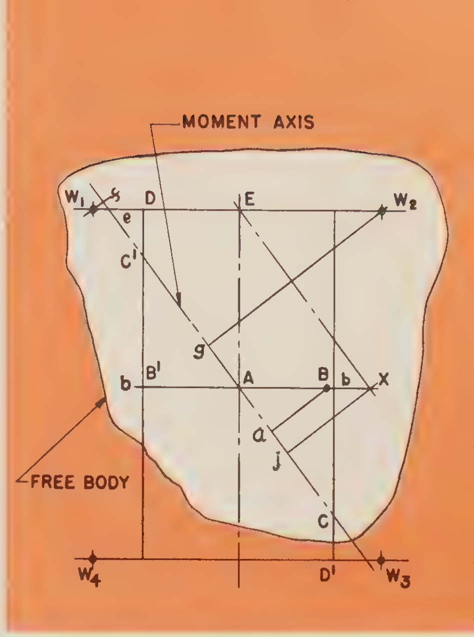


Fig. 2—The apparent symmetrical design suggests that the wheels are equally loaded. Calculations show, however, that this condition does not exist, as the load on wheel W_1 equals *31,000 lb* and on wheel W_2 equals only *19,000 lb.* Equal wheel loading will result when the position of the spring support is moved outward from the center of the truck to the position X. The distance AX is *26.63 in.*

STEP 5—Calculation for jX from moment balance about the moment axis:

$50{,}000 \text{ lb} \times jX + W_1 \times 2.68 \text{ in.} = W_2 \times 45.5 \text{ in.}$
$50{,}000 \times jX = 45.5\ W_2 - 2.68\ W_1$
$W_1 = W_2 = 25{,}000$ lb.
Substituting in the moment equation and solving for jX:
$50{,}000 \times jX = 45.5\ (20{,}000) - 2.68\ (20{,}000)$
$50{,}000\ jX = 1{,}070{,}000$ in.-lb
$jX = 1{,}070{,}000 / 50{,}000$
$jX = 21.41$ in.
Triangle ABa is similar to triangle AXj
therefore, $AX{:}AB$ as $jX{:}aB$
or: $AX = (AB)(jX)/(aB)$
$AX = 19.5 \times 21.41 / 15.68$
$AX = 26.63$ in.

In order, therefore, for the truck design to be such that all wheels will be equally loaded, the distance from the center of the truck to the center of the spring supports must be *26.63 in.* A further check for interference may be necessary but will not be considered in this problem.

A very simple answer for balancing the wheel loads may also be had by drawing the line EX parallel to the pivot axis CAC' and the intersection at X is the proper location for the spring support.

Recent Speaking Engagements Filled by GM Engineers

One of the ways in which information about General Motors engineering developments is made available to interested outside groups is the appearance by engineer-lecturers from the various Divisions and Staffs. In response to requests, these GM engineers speak in engineering classrooms and before technical societies and other organizations. Listed below are a number of such speaking engagements filled in recent months.

On October 9 **Albert E. Fyffe**, executive engineer, AC Spark Plug Division—Milwaukee, outlined "The Electrical System of an Automobile" to a group of Boy Scouts attending the Annual Merit Badge Clinic, held in Milwaukee, Wisconsin.

Dr. Robert W. Smith, research engineer in the Spark Plug Engineering Department at AC Spark Plug, addressed the October 13 meeting of the Society of Applied Spectroscopy in Milwaukee, Wisconsin. The subject of his talk was "Quality Control by Spectrochemistry."

During the Career Conference held in Flint, Michigan, public schools on October 19 and 20, **William J. McBride**, engineer in the Skysweeper Department of AC Spark Plug, discussed "The Opportunities in the Field of Electronics."

Walter F. Eitel, general supervisor of AC Spark Plug's Methods and Layout Department, outlined "How to Establish an Effective Methods Program" during the Association of Management convention held in Toronto, Canada, on October 21.

"The Skysweeper Anti-Aircraft Gun and Its Fire Control System" was the talk given by **John A. McDougal**, AC Spark Plug military products engineer, before the American Institute of Electrical Engineers meeting on October 27.

"Present and Future Use of Digital Computers in Engineering" was the title of the talk presented at Purdue University's Aeronautical Colloqium by **J. T. Horner**, supervisor of the Engine IBM Calculation Group, Engineering Services Department, Allison Division, on October 29.

R. M. Schaefer, manager of the Transmission Engineering Department of Allison, completed three speaking engagements during the period covered in this report. He presented "Transmission Developments for Trucks and Buses" before S.A.E. sections in Houston, Texas, on October 8, and Honolulu, Hawaii, on November 23.

On November 11 he described "The Use and Application of Hydraulic Drives" before the Howie Sugar Technologists in Honolulu, Hawaii.

Two members of the B.O.P. Assembly Division's Kansas City plant addressed the A.S.M.E. meeting in Kansas City, Missouri, on October 25. **T. W. Gillespie**, chief test pilot on the maiden test flight of the F-84F Thunderstreak airplane produced at that plant, described "Production Test Flying." **W. S. Lieberman**, supervisor of engineering flight test, outlined "Engineering Problems Developing from Flight Testing High-Speed Aircraft."

George C. Aitken, assistant staff engineer-in-charge of the Drafting Group at Chevrolet Motor Division's Central Office described "The Corvette Plastic Body" before the American Society of Tool Engineers on October 14 in Rockford, Illinois.

At the American Society of Body Engineers' Technical Convention held in Detroit, Michigan, on October 29, **John G. Coffin**, assistant metallurgical engineer in the Production Engineering Group of Chevrolet, spoke on "The Marriage of Glass and Plastic—A New Body Material."

A. J. Altz, retired assistant chief engineer-in-charge of administration in the Engineering Department of Chevrolet Motor, addressed the Cleveland Engineering Society in Cleveland, Ohio, on November 3. The title of his presentation was "Engineering Management and Today's Economy."

"Stability and Performance on Turns" was the topic discussed at the Senior Mechanical Engineering Seminar at Lehigh University, Bethlehem, Pennsylvania, on November 17 by **Zora Arkus-Duntov**, assistant staff engineer, Research and Development Section, Chevrolet Central Office.

Personnel from Delco Radio Division's Mechanical Engineering Department took part in the Mechanisms Conference held at Purdue University, Lafayette, Indiana, on October 11 and 12. **M. G. Wright**, section head, was a panel member discussing "Mechanism Manufacturing Tolerances" and **W. R. Kearney**, mechanical engineer, discussed "Straight-Line Mechanisms."

J. M. Rodgers, supervisor of electrical process in Delco Products Division's Process Equipment and Layout Department, was a featured speaker at the 42nd National Safety Congress held in Chicago, Illinois. He addressed the Electrical Equipment Section on October 21 on "Is it Safe?—Safety Considerations in Electrical Controls and Product Testing."

Electro-Motive Division personnel who were participating lecturers in a class on "Industrial Applications of the 567 Engine" were: **E. W. Kettering**, chief engineer; **B. B. Brownell**, assistant chief engineer; and **W. King Simpson**, technical director of fuels and lubricants. The class was conducted at LaGrange, Illinois, during the week of October 4-8 for 58 representatives of petroleum companies.

Mr. Simpson also participated in the S.A.E. National Fuels and Lubricants meeting in Tulsa, Oklahoma, as chairman of the morning session on October 12.

K. O. Bower, a-c controls engineer in the Engineering Department at Electro-Motive, demonstrated the Division's new Electro-Mobile Power Units before a group of 100 executives of electric utility companies and representatives of the press at the Division on October 12.

On October 24 **Louis F. Held**, chief product design engineer in the Product Engineering Department of Euclid Division, appeared on WNBK-TV, Cleveland, Ohio. Mr. Held outlined "The Opportunities in the Earth-Moving Equipment Industry" as part of a program to interest high school students in engineering. The program was arranged by the Cleveland Technical Society and the S.A.E.

K. B. Bly, product engineer at Fabricast Division, narrated the film "Production of Buick Dynaflow Castings" for the George Rogers Clark Chapter of the Society of Professional Engineers in Bedford, Indiana, on October 26.

Kenneth E. Coppock, assistant chief engineer, Fisher Body Division, spoke on "Who Is the Designer—the Stylist or the Engineer?" before two groups. On October 12 he addressed the Chicago Section of the S.A.E. in Chicago, Illinois, and on October 29 he appeared before the American Society of Body Engineers' Technical Convention in Detroit, Michigan.

On October 22 **Harold V. Beckerleg**, engineer-in-charge of the Engineering Laboratory of Fisher Body, discussed "Rubber and Plastic Foam in the Automotive Industry" at a joint meeting of the Akron Rubber Group and the Society of Plastic Engineers held in Akron, Ohio.

Two additional Fisher Body personnel addressed the A.S.B.E. Technical Convention in Detroit. On October 27 **Karl S. Horvath**, production engineer, Production Engineering Section, spoke on "The Pre-Production Pilot-Body Program" and on October 29 **Ronald D. Beck**, senior process engineer, Development Engineering Department, described "Plastic Models and Fixtures."

On November 4 **Charles A. Chayne**, vice president in charge of the General Motors Engineering Staff, addressed the Los Angeles Air Pollution Control Association. He discussed "Motor Vehicles and the Air We Breathe."

Howard K. Gandelot, engineer-in-charge of the Vehicle Safety Section of the Engineering Staff, GM Technical Center, completed two speaking engagements during the period covered in this report. On October 26 he spoke on "The Vehicle in the Traffic Safety Equation" at the Annual Meeting of the National Association of Independent Insurers held at St. Louis, Missouri. At the 1954 Conference for Safer Living held in New York from November 8 to 10 he discussed various aspects of safe driving: "Motor Vehicle Designs from a Safety Consideration," "Development of Driver Skills," and "Future Trends in Driver Training and Education."

D. B. McCormick, section engineer in the Automotive Ordnance Group, Engineering Staff, discussed "Development and Engineering of a New Ordnance Vehicle to Specifications" before the American Ordnance Association in Cincinnati, Ohio, on October 7.

Three members of General Motors Manufacturing Staff made presentations during the period covered in this report. **John M. Duncan**, industrial engineer, spoke on "What's New in Industrial Engineering" before the Niagara Frontier Society and the University of Buffalo's Industrial Engineering Conference at the University of Buffalo, Buffalo, New York, on October 6.

R. D. McLandress, director of the Work Standards and Methods Engineering Section, described "The Organization and Coordination of Industrial Engineering Functions in a Large Corporation" at the 18th Annual National Time and Motion Study and Management Clinic held in Chicago, November 12.

On November 15 **Arthur B. Wright**, methods engineer, appeared before the annual convention of the Michigan Hospital Association held in Detroit. He spoke on "The Concept of Methods Engineering in a Manufacturing Organization."

A fourth speaker from the Manufacturing Staff was **L. J. Pedicini**, senior foundry engineer in the Process Development Section. He discussed "Shell Molding" at a joint meeting of the American Foundrymens Society and the American Society of Metals in Minneapolis on October 12.

David C. Apps, head of the Noise and Vibration Laboratory, GM Proving Ground, Milford, Michigan, participated in the Fifth National Noise Abatement Symposium held in Chicago on October 22. The title of his presentation was "Quieter Automotive Vehicles."

Before the American Society of Body Engineers in Detroit, Michigan, on October 27, **William L. Mitchell**, director of General Motors Styling Section, spoke on "Automobiles—The Nation's Outstanding Commodity."

G. T. Christiansen, staff assistant in the Styling Section, read R. F. McLean's "An Aerodynamic Design in Plastics" before the Detroit Section, S.A.E., in Detroit on October 4.

Floyd A. Franklin, coach engineer in the Coach Engineering Department at GMC Truck and Coach Division, participated in the S.A.E. National Transportation Meeting held at Boston, Massachusetts, on October 18. He presented a discussion of the paper by Joseph M. Sills, assistant to the president of the Greyhound Corporation, covering two-level intercity coaches.

On October 11 **George W. Onksen**, research engineer in the Engineering Department of Guide Lamp Division, outlined "The Development of the Guide Lamp Autronic-Eye Automatic Headlamp Control" before the Student Chapter of the Radio Engineering Society at Tri-State College, Angola, Indiana, on October 11.

H. A. Reynolds, assistant chief product engineer, Automotive Section, Harrison Radiator Division, addressed the Fifth Year Engineering Students at Cornell University, Ithaca, New York, on November 12. The subject of his talk was "Automotive Cooling System Design."

The Whirlfire gas-turbine engines, which were designed at the Research Laboratories Division and power the Firebird car and the Turbocruiser bus, were the subjects of the talk "Pinwheels or Pistons" presented before several groups during this period.

W. A. Turunen, head of the Gas Turbines Department, Research Laboratories Division, delivered the talk before S.A.E. sections in Detroit, Michigan, on October 4, in Cincinnati, Ohio, on October 25, and in Milwaukee, Wisconsin, on November 5. **John Collman**, assistant head, made a similar presentation on October 4 in Pittsburgh, Pennsylvania, at the American Transit Convention and on the same date appeared at a meeting of the Williamsport, Pennsylvania, Section of the S.A.E. He repeated the presentation in Los Angeles, California, on October 11 at a regional meeting of the S.A.E.

Other Research Laboratories personnel made speaking appearances as follows:

On October 7 **Wardley McMaster**, assistant head of the Chemistry Department, appeared before the Technical Paint Forum, Bureau of Standards, in Washington, D. C., to discuss "Five Percent Salt Spray and Its Acidic Acid Modification."

Members of the Philadelphia Section of the S.A.E. heard **Darl Caris**, head of the Automotive Engines Department, discuss "Future Trends in Engine Progress" on October 14. He repeated this talk in Galveston, Texas, on October 22 at a meeting of the American Institute of Chemical Engineers.

Members of the Physics and Instrumentation Department appeared before the Electron Microscope Society of America held on October 14-16 in Highland Park, Illinois. "Preparation of Lubricating Oils and Liquid Fuels for Electron Microscopy" was the title of a paper prepared by **William L. Grube**, supervisor; **Stanley Rouze**, research physicist; and **F. Agnes Forster**, special tester.

Harold L. Schenk, research physicist, presented "Quantitative Determination of Cementite in Steel by Light and Electron Metallography" at the same meeting.

Several members of the Mechanical Development Department presented papers during this period. **Worth Percival**, supervisor, appeared before the S.A.E. meeting in Cleveland, Ohio, October 26 to 28, to describe "Method of Scavenging Analysis for Two-Cycle Diesel Cylinders."

Robert Davies, research engineer, discussed "Hydrodynamic Lubrication of a Cam and Cam Follower" on October 19 at the American Society of Mechanical Engineers' Lubrication Conference held in Baltimore, Maryland.

T. A. Boyd, Research Laboratories consultant, addressed the student body at the University of Oklahoma, Norman, on October 21. The two talks which he delivered were "Get Off Route 25" and "The Engineer in the Research Business."

A.S.R.E. Award Made to GM Engineer

The American Society of Refrigerating Engineers has selected for its 1954 "Best Section's Paper Award" a paper by J. Ralph Holmes, chief engineer of Harrison Radiator Division, General Motors, Lockport, New York. Mr. Holmes' paper, entitled "Air Conditioning the Automobile," was presented at a joint meeting of the Buffalo and Toronto Sections held in Lockport on May 7, 1954. The award was presented to Mr. Holmes at the Society's 50th Annual Meeting held in Philadelphia on November 29.

The paper discussed the multiple problems which confront the air conditioning engineer in the relatively new field of automobile air conditioning. Another of Mr. Holmes' papers dealing with the same subject matter is planned for a future issue of the GENERAL MOTORS ENGINEERING JOURNAL.

Contributors to

GENERAL MOTORS Engineering JOURNAL

January-February 1955

ARTHUR J. ALTZ,

contributor of "Some Personal Lessons from Five Decades in Engineering," was, at the time of his retirement on December 31, 1954, assistant chief engineer in charge of administration in the Engineering Department of Chevrolet Motor Division. In this position he directed a number of activities which are necessary services for the work of the Chevrolet Central Office Engineering Department as a whole. Such services include drafting, records, experimental fabricating, interdepartmental liaison, and execution of Divisional policies in the Department.

Of the nearly 50 years which Mr. Altz had devoted to engineering work, 32 years were spent with the Chevrolet Motor Division. He began as a designer in 1922 and advanced through the organization in various steps to the position he held at the time of his retirement. Part of this experience was the supervision of drafting in the Engineering Department and he made substantial contributions to the organization of this work for the Division and later headed the editing of the General Motors Drafting Standards, used as a guide throughout the various GM Divisions.

Mr. Altz's career began as a messenger boy at the Packard Motor Car Company in 1907. He rose to the position of designer and, in 1917, he left Packard to take a position as chief draftsman at the Isko Company. He remained with this firm until 1919 when he joined GM. He was employed as a designer by a GM unit known as Sunnyhome Electric Company of Detroit. One year later he transferred to the Allen Tractor Division where he remained until 1921. He then transferred to Chevrolet for a period of a few months after which he transferred to Harrison Radiator Division. He returned to Chevrolet in November 1922.

Mr. Altz is the author of several papers including "Drawing in the Defense Industries," published in the *Journal of Engineering Education*, American Society for Engineering Education, and "Engineers—How They Function," presented to the 1954 GM Conference for Engineering Educators.

ROBERT W. FORWARD,

contributor of "A Discussion of Design Principles and Their Effect on Economical Processing of Molded Plastic Products," is a junior process engineer in the Process Engineering Department at Inland Manufacturing Division, Dayton, Ohio. He assumed this position upon graduation from General Motors Institute in August, 1953 with the Bachelor of Industrial Engineering degree.

Mr. Forward, who was sponsored by Inland Manufacturing as a G.M.I. cooperative student, fulfilled various work assignments in engineering, research, accounting, manufacturing, sales, and personnel administration while completing his four years of undergraduate studies. His undergraduate work was followed by the Fifth-Year Program which provided full-time work experience in a definite field combined with a project study. His particular field of specialization was in the area of plastic and rubber product processing and the subject of his paper is based on the thesis he prepared in connection with G.M.I. requirements leading to the granting of engineering degrees.

Mr. Forward's current work is concerned with the continuation of effecting more economical processing procedures for both plastic and rubber products through the study of improving design principles.

This is the first technical paper Mr. Forward has had published. His technical affiliations include membership in the Ohio Society of Professional Engineers.

LOUIS C. LUNDSTROM,

contributor of "Applied Basic Mechanics Solves a Civil Engineering Problem on Super-Elevated Curves of Proving Ground Test Track," has spent his entire career at the General Motors Proving Ground, Milford, Michigan, where he now serves as assistant director.

Mr. Lundstrom came to the Proving Ground in 1939 as a test engineer after being graduated from college. Six years later he was made head of the Mechanical Engineering Department and he assumed his present position in 1953.

The military testing of transmissions and power trains was part of the work assigned to Mr. Lundstrom during World War II when he was project engineer. Later, the Cadillac Tank Plant in Cleveland required his services to handle special problem assignments. Among the major projects which have drawn Mr. Lundstrom's attention has been automotive test equipment design and development. He also directed the modification of road-paving machinery for the purposes outlined in his current paper.

Mr. Lundstrom was graduated from the University of Nebraska with the B.S. degree in mechanical engineering and the M.S. degree in engineering.

He is a member of the Society of Automotive Engineers and serves on this Society's Construction and Industrial Technical Committee, Transportation Engineering Formulas Subcommittee, and Highway Research Board Project Committee 14 on Speed Characteristics. He also is a member of the Engineering Society of Detroit, American Ordnance Association, Sigma Tau national honorary engineering society, and Sigma Xi.

BERTRAM A. SCHWARZ,

contributor of "A Survey of the Transistor," is chief engineer at Delco Radio Division, the position he has held since joining the Division in 1936. During that same year the Division was reorganized under its present name, having been known previously as the General Motors Corporation Radio Activity.

Mr. Schwarz's developmental work in the radio industry has resulted in the granting of 26 patents in the fields of radio, electronics, tuning systems, and loud speakers. Among the projects carried out under his supervision at Delco Radio have been those related to radar and counter-radar devices as well as automobile radios, military electronics and communications, and transistors—the subject of his paper in this issue.

His experience before joining General Motors included direction of engineering work at two other organizations. He was chief engineer of the Automobile Radio Division of the Zenith Radio Corporation, Chicago, Illinois, for a two-year period and he served for five years as vice president in charge of engineering, Consolidated Industries, Limited, Toronto, Ontario.

The grade of Fellow has been conferred upon Mr. Schwarz by the Institute of Radio Engineers, effective January 1, 1955. The technical and professional groups in which he participates include the Acoustical Society of America (member society of the American Institute of Physics), the Professional Group of the I.R.E., the Receiver Executive Committee of the Radio-Electronics-Television Manufacturers Association, and the Mechanisms Conference Committee (sponsored jointly by Purdue University, *Machine Design* magazine, and industry). Mr. Schwarz also serves as vice chairman of the Radio-Electronics-Television Manufacturers Association Vehicular Committee.

HAROLD G. SIEGGREEN,

contributor of "How the Shell Mold Process Is Applied in Industry," serves as chief engineer of Central Foundry Division, Saginaw, Michigan. In this capacity, he has responsibility for the Division's product engineering work and for the Experimental Foundry, where many of the shell mold applications described in his paper were developed. The chief engineer also serves in a consulting capacity in connection with engineering projects in the Division's plants. Much of his technical work is outside the Division, working with the product engineers and tooling departments of customer organizations to advise on the manufacturability of proposed parts.

Mr. Sieggreen came to the Division's Saginaw Malleable Iron Plant in 1931 as a journeyman machinist who wanted to study automotive engineering. He became a General Motors Institute cooperative student and completed the automotive engineering program in 1935. Then, as foreman of maintenance and later of the pattern shop, he specialized in pattern and equipment design for green sand molding. This activity has continued throughout his career but, since 1949, he has devoted his major attention to improving the shell mold process and its applications. His positions at the Malleable Iron Plant also included production standards and methods supervision and inspection contact work with customers. In 1943, when the Plant was entirely in war work, he became process engineer and in 1947 moved to the Division's Central Office as chief process engineer. He was appointed chief engineer in January 1953.

While at G.M.I., Mr. Sieggreen was elected to Alpha Tau Iota honorary society and became a member of the Society of Automotive Engineers. He has served on the Educational Committee of the American Foundrymens Society and is a member of the American Ordnance Association. He has delivered several papers on foundry topics before A.F.S. and S.A.E. audiences.

IVAN H. SPOOR,

who prepared the problem "Find the Wheel Loads of a Railway Truck of Novel Design" and the solution appearing in this issue, serves as chief calculator in the Engineering Department's Calculation Group of Electro-Motive Division, La Grange, Illinois. The problem and solution he presents are typical examples of the Calculation Group's role in the design phase of an engineering project. Mr. Spoor's current projects include calculations pertaining to most of the new projects which Electro-Motive is now developing.

Mr. Spoor was originally employed by Electro-Motive as a draftsman in

1936, one year after this Division moved from Cleveland, Ohio, to La Grange. Regular promotions have led to his present position which he assumed in 1951. Some of the major projects which Mr. Spoor has previously been concerned with include locomotive and car-body stress analysis and Diesel engine balance and torsional vibration analysis.

Prior to joining Electro-Motive, Mr. Spoor had over twenty years of experience in tool design, production engineering, and plant supervision. His experience pertaining to tool design was acquired when he was employed by the R. Krasberg & Sons Manufacturing Co., Chicago, Illinois. While working for the R. R. Donnelley & Sons Co., Chicago, he became familiar with production engineering and he gained experience in plant supervision while employed by the Gerrard Steel Strapping Division of the U.S. Steel Corporation, Chicago.

Mr. Spoor's work at Electro-Motive has resulted in the granting of six patents pertaining to wire forming and handling machines.

Mr. Spoor was graduated from the University of Wisconsin in 1910 with the B.S. degree in mechanical engineering and as a student was elected to the Tau Beta Pi honorary society.

DUWARD C. STALEY,

contributor of this issue's "Notes About Inventions and Inventors," is a patent attorney in the Dayton Office of the Patent Section. He was originally employed in 1926 as patent draftsman with the Patent Section of Delco Products Division. The next year he transferred to Frigidaire's Patent Section, working in the capacities of patent draftsman, engineering contact, and, upon his completion of law studies, patent attorney.

In 1940 Mr. Staley left General Motors to join a patent law firm in Dayton. During this time he became a member of and practiced before the U. S. District Courts, U. S. Courts of Appeal, and the United States Supreme Court. Twelve years later he returned to GM to assume his present post in the Dayton Office of the Patent Section. In this position he handles patent matters for Delco Products Division—electric motors, generators, shock absorbers, motor starter controls; Moraine Products Division—brakes, brake boosters, and brakes for the several automotive Divisions of General Motors; and Packard Electric Division—connectors, harnesses, and light sockets.

Mr. Staley studied law at Wittenberg College and the University of Dayton and was granted the L.L.B. degree from the University in 1936. He is a member of the bar of the State of Ohio, the American Bar Association, the Ohio State Bar Association, Dayton Bar Association, Dayton Patent Law Association, the Dayton Engineers Club, and a past member of the American Society of Mechanical Engineers.

GEORGE E. TOZER,

contributor of "A Study of Applied Gear Design: Speedometer Gears of Different Ratios in Pontiac Transmissions," is a designer in the Chassis Section of the Pontiac Motor Division Experimental Engineering Department. He has been engaged in design engineering work since his graduation in 1952 from General Motors Institute. His interest in gears originated with a gear design course taken at G.M.I. Since then he has been involved with many gear problems at Pontiac Motor which include most phases of automotive application. This experience has been broadened by a survey study of hypoid rear axle gears at the Gleason Works in Rochester, New York.

Mr. Tozer joined General Motors in 1946 as a draftsman at Chevrolet Division in Cleveland, Ohio, immediately following his discharge from the Navy. He transferred to Pontiac Motor in 1947 and, under the sponsorship of Pontiac Motor, he entered General Motors Institute in 1948. He completed the four-year program in automotive engineering in 1952 and earned his bachelor of mechanical engineering degree in 1953 through the G.M.I. Fifth-Year Program.

While at G.M.I., Mr. Tozer was editor of the school paper, *The Technician;* president of Delta Chapter of Alpha Gamma Upsilon Fraternity; chairman of the S.A.E. Student Chapter; and treasurer of the Inter-Fraternity Council.

Besides his gear design work, other projects with which he has been concerned include steering geometry applications, throttle control linkages, and brake designs. Mr. Tozer holds a junior membership in both the Society of Automotive Engineers and the Engineering Society of Detroit.

VICTOR A. WILLIAMITIS,

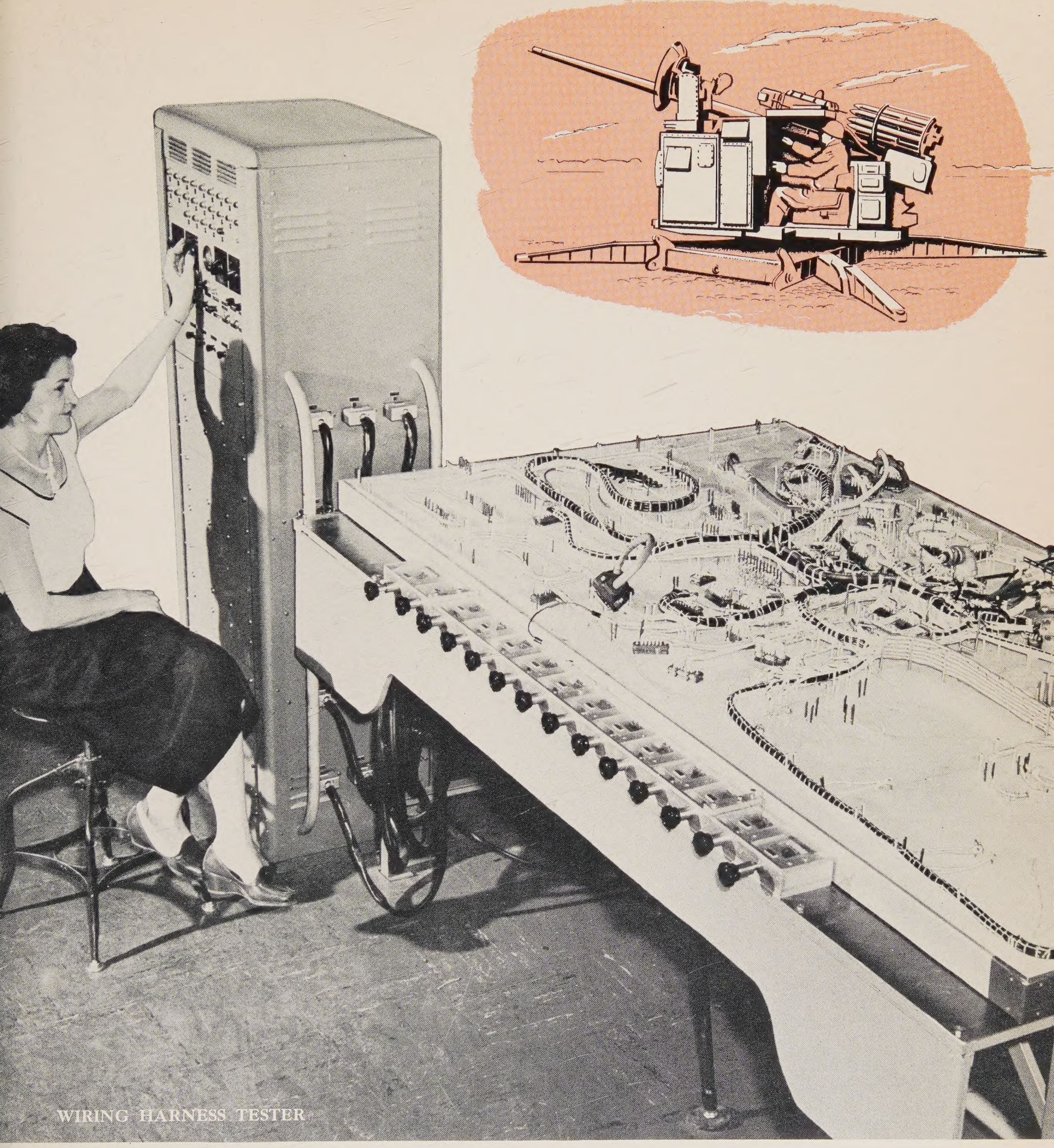
contributor of "How Chemical Stability Assures Long, Attention-Free Performance of Sealed Refrigeration Systems," is senior experimental chemist with the Materials and Process Engineering Department of Frigidaire Division. Mr. Williamitis joined Frigidaire in 1936 as a summer student laboratory assistant and later worked as a chemist in the control laboratories. He was enrolled during this period at the University of Dayton where he was graduated in 1938 with the degree of Bachelor of Chemical Engineering.

Following graduation, he joined Frigidaire's Engineering Department on a full-time basis. Since then, he has been concerned with the materials problems of refrigeration systems and other Frigidaire products. His work has included factory process development as well as material research, and one of his past projects was the improvement of cleaning, pickling, and nickel application processes prior to porcelain enameling. This project resulted in substantial reduction of porcelain flaws and improved bonding.

During World War II, he was associated with the Army Ordnance Department and later with the Transportation Corps as a specialist in corrosion prevention and packaging problems of Armed Forces materiel.

Mr. Williamitis has made a number of speaking appearances in recent years related to corrosion prevention, processing and packaging, and flexible connectors for mobile air conditioning units. In addition, he has made appearances of a civic nature in connection with his activities as president of the Dayton Sightless Children Club.

He is a registered professional engineer and is listed on the Roster of Manufacturing "Know How" for the Cincinnati Ordnance District.



WIRING HARNESS TESTER

A complex wiring harness, used in the operation of radar and computer components of the 75 mm Skysweeper anti-aircraft gun, is laid out on this table to undergo a test for "shorts" and breaks.

The test is made automatically by the electronic device shown at the left, developed and put into use by AC Spark Plug Division which manufactures the fire control system for this U. S. Army weapon. The testing device, called a *hipot*, is an automatic high potential and continuity tester which is connected to the wiring harness through the row of plug-ins on the table (foreground). A short or break in any wire is indicated visually in the row of lights above the operator's hand. The important advantage of the hipot in the production of defense materials is the saving of time required for testing complex wiring harnesses. Former test procedures required 40 hours for some harnesses but now the same harnesses can be tested by the hipot in one hour.

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